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WATER AND LAND IN SOUTH AFRICA: ECONOMY-WIDE IMPACTS OF REFORM
A Case Study for the Olifants River

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Introduction

South Africa's legacy of apartheid has profound implications for natural resource use. Under apartheid, the State decided which economic and social sectors it would favor, articulate specific policies which would allow these sectors to thrive, mobilize physical and financial resources in support of the sectors, and articulate legislation to facilitate the process. The access to natural resources in South Africa today continues to be a direct result of the country's long history of selective favoritism.

In 1994, the Government of National Unity (GNU) launched its Reconstruction and Development Progamme (RDP). It is an wide-reaching program, intended to dismantle the economic and political structures that South Africa inherited from its apartheid past. Equitable, efficient control and access to natural resources are correctly viewed by the GNU as prerequisites to future economic growth. Fundamental principles and objectives to guide South Africa's future have been outlined in various RDP 'White Papers' (on issues such as land and water), yet little quantitative work has yet been done to determine the possible costs and trade-offs associated with these principles and objectives.

This paper presents a "Watershed Computable General Equilibrium (CGE) Model" for the Olifantsriver Catchment in the Transvaal, and is based on research conducted for my PhD dissertation (1996). A CGE was chosen as the analytical tool, because it provides an appropriate framework in which to explore possible policy alternatives for achieving more efficient water and land use.

South Africa's water use patterns

In light of the country's past, it comes as no surprise that water distribution in South Africa is extremely inequitable. Presently, water supplies favor commercial agriculture, industry, and in the Eastern Transvaal, electricity-generation. This pattern of water consumption comes largely at the expense of domestic water consumption for a sizable portion of the black population. According to estimates cited in the "Water Supply and Sanitation White Paper", approximately 12 million people (over 40 percent of the total black population of the country) lack domestic water supplies, and 21 million (roughly 75 percent of the black population) lack basic sanitation services (White Paper, 1995, p.5).

This situation is especially disturbing, when one is reminded that water use in agriculture exceeds human consumption by a factor of three (World Bank, 1994, p.32). According to the World Bank, at existing water use rates in South Africa, it is estimated that the average irrigation water use of one hectare of land for one growth cycle would be sufficient to meet the domestic needs of almost 900 people for one year. In fact, commercial farmers are the biggest users of freshwater in South Africa. With an estimated gross average application of 7,877 cubic meters per hectare on a total irrigable area of 1,231 million hectares, they account for 67 percent of all *directly* used water in South Africa (Table 1).

Until the late 1980s, the distorted price structures for agricultural inputs and outputs contributed to perverse producer incentives. With a subsidy package that lowered the cost of credit, irrigation capital and water, it was common to find such low-value products as grass meadows and forage crops under irrigation. Additional price supports for many crops encouraged excessive irrigation on lands that are better suited for other purposes. To compound the problem, irrigation efficiency in South African agriculture is quite poor. One study suggests that nearly half of the irrigation water released from public dams is wasted (Backeberg, 1993, p.18).

The other economic sector that is viewed as a threat to South Africa's water resources is the commercial forestry sector. The sector is blamed for severe reductions in surface water runoff. Today, only about 250,000 hectares of indigenous forests remain in South Africa. In contrast, about 1.2 million hectares are under pine and eucalyptus - exotic species that are much thirstier than indigenous species - and a further 30,000 hectares are estimated to being added annually, to meet the pulp and paper needs of the industrial sector. Under current plans, it is reported that the forestry industry will double its current plantation area of 1.2 million hectares in the next three decades (World Bank, 1994c, p.9). Many agree that these plans do not bode well for water availability in the future.

Table 1 shows in more detail water use by different economic sectors in South Africa in 1990, and predicted changes in the next 20 years. The other major users of water, listed as 'indirect' by the Department of Water Affairs and Forestry are forestry, estuaries and lakes.

Integral to the inefficiency and inequality of South Africa's water policy are the laws on which water ownership are based. The current legal framework on which water management is based has permitted a situation where land owners are pumping rivers dry. The accelerated rate of groundwater abstraction, in addition to the construction of private dams, has resulted in a dramatic decrease in the amount of water reaching the rivers. It is estimated that over 65 percent of all water currently used in rural South Africa is either 'private' water or water obtained via riparian rights (ECE Ltd., 1993). (See Annex 1 for an short overview of water and related legislation).

Water availability

The scope for securing additional water supplies to fulfill increased future water demand in South Africa is quite limited since the country's hydrological conditions are not especially favorable. A considerable area of South Africa is classified as arid or semi-arid; only 13 percent of South Africa's total surface area is considered to be arable (World Bank, 1994). Rainfall is unevenly distributed with 65 percent of the country receiving less than 500 millimeters of rain annually. As conditions get drier toward the west, the variability of precipitation also increases. Average annual evaporation ranges between 1,100 millimeters to more than 3,000 millimeters, which is well in excess of average annual rainfall. There are few freshwater lakes in South Africa. Exploitable water supplies are therefore largely confined to rivers and groundwater.

Table 1: Water use by economic sectors in South Africa, 1990 and 2010

Demand sector	1990 (million m3/annum)	% of total, 1990(actual)	2010 (million m3/annum)	% of total, 2010 (est.)
Direct Uses:				
Municipal & domestic	2,281	12.0	4,477	17.3
Industrial	1,448	7.6	2,961	11.4
Mining	511	2.7	649	2.5
Electricity generation	444	2.3	900	3.5
Irrigation	9,695	50.9	11,885	45.9
Stock watering	288	1.5	358	1.4
Nature conservation	182	1.0	191	0.7
Indirect Uses:				
Forestry	1,427	7.5	1,700	6.6
Estuaries/lakes	2,767	14.5	2,767	10.7
TOTAL	19,043	100.0	25,888	100.0

Source: Department of Water Affairs.

It has becoming clear - even to privileged, 'well-watered' parts of South African society that - given the country's natural conditions and man-made institutions - current water allocation and water management schemes are not sustainable, neither from an economic, socio-political nor environmental point of view. The GNU is committed "to ensure that all South Africans have access to essential basic water supply and sanitation services at a cost which is affordable both to the household and to the country as a whole." (Water Supply and Sanitation White Paper, 1995, p. 5). The White Paper states that "...water for domestic or 'primary' consumption always receives priority"(White Paper, 1995, p.8). In fact, the GNU's Minister of Water Affairs, Kader Asmal, has even proposed that "a reliable and unpolluted supply of water" be considered not just a desirable goal, but a fundamental human right that should be captured in the country's permanent Constitution, which is to replace the current Interim Constitution in 1999 (Asmal and Roberts, 1994). By Department of Water Affairs and Forestry estimates, water for human consumption represents only a small fraction of total available water supplies, which - in principle and with the proper reforms- can be satisfied without impinging on water use for the economic sectors.[1]

However, there remain many unexamined and unanswered questions as to what should happen *after* the fulfillment of human water needs. Some policymakers suggest that the agricultural sector - especially - should receive water allocations that are more in line with the sector's economic returns. Even if the agricultural sector in South Africa were to be drastically re-structured - say, in favor of small-scale and black farmers - there are others who doubt that "there exists a clear rationale for allocating even more water to agriculture for intensification." (McKenzie, 1993) Worthier uses of water are commonly considered to be industrial (such as for electricity generation and mining), environmental and use for forestry and eco-tourism.

Research questions and hypotheses

In essence, the basic questions that need to be asked when considering appropriate water reform measures are: How should the remaining available and existing water supplies be re-allocated among alternative uses, both productive (in economic sectors such as agriculture, mining, industry and tourism) and consumptive (both for human and ecological use)? What should the new rules governing water use be? What will be the main criteria that guide the formulation of these new water rules?

Fundamentally, the new rules will need to find an acceptable compromise between economic efficiency and economic equity. In a purely economic sense, if water is the scarcest input - relative to other factor inputs - then it should be allocated to that activity that yields the highest economic return, with respect to water. Water allocation on the basis of economic returns alone, however, may have undesirable implications for equity. The economic use of water by one user may be accompanied by a social cost to another. Obviously, it is imperative for policymakers to understand the nature of the trade-off that characterizes new water rules. Before new allocation rules and mechanisms for water use are formalized, research should attempt to determine which of them is best suited to mitigate the problems of water scarcity. To date, little is known about the magnitudes of the trade-offs that are associated with alternative water distribution policies.

It is entirely possible that water reforms could lead to improved economic efficiency *and* equitable growth. With water reforms, water will be allocated away from the more inefficient to the more efficient users of water. According to proponents of the "inverse farmsize-productivity

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[1] Present water use in South Africa amounts to nearly 50 percent of available runoff and groundwater, and this, by South Africa's Department of Water Affairs and Forestry, is likely to rise to about 67 percent by 2010. This estimate suggests that water availability from surface and groundwater sources will comfortably accommodate economic and population growth, but it must be pointed out that several regions of the country are already experiencing severe shortages. Gauteng province (formerly called the PWV region) with its big cities of Johannesburg and Pretoria, already uses far more than 100 percent of locally available water, and extra water has to be imported from the Usutu and Tugela rivers.

relationship"[2], smaller economic units are argued to be more efficient users of factors like capital and water, than are larger economic units. If, in fact, this hypothesis is true, then with increased water scarcity that forces increased water use efficiency, smaller economic units (such as in this Water CGE model, productive units in 'homeland' agriculture) are better suited to weather the "shock" of water reforms.

If South Africa were to institute policies to improve current water management practices - such as by moving in the direction of water markets, for example - the following hypotheses (concerning changes in water allocation and management) could be postulated:

The increased marketability of water will realize substantial efficiency gains in all sectors, but particularly in agriculture. Efficiency gains mean that the value of output relative to the value of inputs will increase when water is valued at its marginal product. When water has a real opportunity cost for those users that currently use it as if it were a free resource, the overall input mix will change so as to most profitably utilize the water.

Water, as a factor input, will be allocated away from the commercial, large-scale agricultural sector in the watershed, to the other sectors within the watershed.
It should be mentioned that this shift, in fact, is a trend that is presently observed. Water sales, especially in the recent periods of drought, are said to be common. Anecdotal evidence suggests that especially cash-strapped commercial farmers benefit from sales of their water allotments (if they operate in an irrigation district or a government water control area) to either more affluent farmers, or to mining enterprises.

Within the agricultural sector, water will be allocated away from large-scale, commercial farms, and allocated to small-scale farms, because profits per unit of water used will be higher for small-scale farms than for large-scale, commercial farms. Instead of using a partial measure, such as agricultural output per unit of water, the more relevant measure to examine overall efficiency of water use, is profit per unit of water. It is hypothesized that small-scale farms have lower costs than the larger, more expensive, capital-intensive commercial farms - giving the former a higher profit per unit of water.

It is postulated, that in light of this relationship, water will see a shift within the agricultural sector, away from large-scale, commercial farms, and towards small-scale farms. Concomitant with this shift from large to small-scale farming is a shift in agricultural cultivation.

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[2] In the field of agricultural economics, the "inverse farmsize-productivity relationship" is a well established topic of discourse. Supporters of this relationship argue that smaller farms are more efficient than larger ones; they claim that most agricultural economists have routinely analyzed either physical yields of specific crops or values of agricultural output, per unit of operated area, but these, they say, are only partial productivity indices. These measures do not take into consideration differences in input and labor use by varying farm size, and therefore should not be regarded as the relevant measures of overall efficiency. It is argued that the correct approach would be to measure ***net*** profits - per unit area or per unit of capital investment, for instance. Using this measure instead of yield per unit area or value of output per unit area, researchers such as Binswanger and Rosenzweig (1986) have gathered evidence that suggests that the larger the scale of a farming operation, the lower the net profits per unit area. In most instances, this is attributed to overall higher capital costs.

Grains, for example, with a small net margin per unit of water use, will give way to the cultivation of high-value crops, such as fruits and vegetables.

Sectoral employment will shift in accordance with water allocations: away from agriculture to other sectors that use water more productively. This hypothesis is a reformulation of the preceding hypotheses. At first, the economic sectors will substitute away from the increasingly expensive water resource. As income effects become more dominant than substitution effects, employment patterns will mirror the shifts occurring when water becomes the most constrained resource. Or alternatively, employment will shift from the agricultural sector to the other sectors, such as mining and industry.

Analytical tool

The motivation for this research was to combine the unique South African problem-setting regarding water management and water allocations with an appropriate analytical framework which would allow the examination of economy-wide effects of policy changes, such as land and water reforms. As the largest water user, the agricultural sector was given a more detailed technical specification. However, since much of the debate concerning reformed water allocations is concerned with economy-wide and issues, non-agricultural uses of water also feature in the Water CGE model.

A CGE model is the economist's version of a laboratory in which it is possible to conduct experiments. First, the model translates the textbook description of an economy - with utility-maximizing consumers and profit-maximizing producers - into a mathematical format. Then, it allows the researcher to *shock* the system, in order to evaluate the economy-wide effects of the shock.

The economic evaluation of any shock - or policy reform - shares all the challenges of evaluating any type of project. This premise is adeptly stated by Varian: "We start from a simple methodological premise: there is only one correct way to do cost-benefit analysis. First, formulate an economic model that determines the entire list of prices and incomes in an economy. Next, forecast the impact of some proposed change on this list of prices and incomes. Finally, use the utility functions of the individual agents to value the pre- and post change equilibria. The resulting list of utility changes can then be summarized in various ways and presented to decision makers." (Varian, 1989)

A CGE framework incorporates more completely than any other framework, the entire list of prices and incomes, as Varian describes it. The relatively wider scope of a CGE model makes it especially useful for evaluating projects that have wide-reaching effects, which change prices and incomes in many sectors through intersectoral linkages. When the policy changes are believed to be large, then a general equilibrium framework is certainly the appropriate tool of analysis.

In the field of water economics, in particular, the CGE framework has hardly been used, even though it lends itself ideally to the issue of economy-wide water allocations and water management. Berck *et al* (1991), Robinson and Gelhar (1995) and Löfgren (1995) are among the few works to use the CGE framework to examine water allocation issues. Their respective model specifications, however, consider only agricultural uses of water. Although several CGE models for South Africa have been formulated, most of these works examine economy-wide and macroeconomic issues (van der Mensbrugghe (1994), Gelb, Gibson, Taylor and van Seventer (ca. 1995)) with no specific emphasis on agriculture or natural resource use.

The watershed and the technical specification of the model

The Water CGE model extends a standard neo-classical CGE model, by nesting into that structure an activity-analysis, programming representation of water and land use. The region captured in the Social Accounting Matrix (SAM) - which serves as the underlying database for the model - approximately coincides with the Olifantsriver Watershed in the Transvaal (see map). The watershed drains an area of approximately 5 million hectares, which corresponds to about 4 percent of the total area of the Republic of South Africa. Roughly a quarter of the area of the Olifantsriver Watershed comprises the former 'homelands' (in current South African policy-speak, this word elicits highly charged reactions, and is therefore used with quotation marks) of Lebowa, KwaNdebele and Gazankulu. Accordingly, over 90 percent of the watershed's total population is African - nearly 80 percent of the African population lives in rural areas. About three-quarters of the area of the Watershed is in what formerly was considered the Republic of South Africa, which did not include the 'homelands' in its formal definition.

The larger urban centers of the watershed are Witbank, Middleburg, Lydenburg, Belfast and Phalaborwa. Although the watershed would be characterized as agricultural, agricultural output constitutes only about 2.5 percent of total regional output. About 95 percent of the Watershed's agricultural areas is under 'fieldcrop' cultivation, where maize is the most important crop. Government supported irrigation schemes govern around 103,000 hectares of the Olifantsriver Watershed. Value-added from the manufacturing and the service sector constitutes 40 and 31 percent of total regional value-added, respectively. Mining is a relatively important sector (with approximately 300 establishments in the region): nearly 9 percent of total value-added stems from this sector. Also noteworthy are the 8 major power stations in the southern part of the watershed; their output constitutes approximately 5.5 percent of the region's total value-added.

On the production side of the SAM and the Water CGE model, there are ten economic sectors (Table 2). The agricultural sector is disaggregated into four sub-sectors: field crops, horticultural crops, livestock and 'homeland' agriculture. The other six sectors of the Water CGE model are non-agricultural.

The Water CGE model specifies three broad categories of factors used in all production processes (Table 3). These are capital, a land-water aggregate, and labor. The labor category is subdivided into thirteen different sub-categories, denoting labor's wide spectrum of skill levels. Only the land-water aggregate has subfactors associated with it: land and water.

Table 2: Economic sectors

1. Field crop agriculture
2. Horticultural agriculture
3. Livestock agriculture
4. 'Homeland' agriculture
5. Mining
6. Manufacturing
7. Transport
8. Electricity and water
9. Construction
10. Services

Table 3: Factor inputs

1. Capital
2. Land-water aggregate
    a. Subfactors: Land, water
3. Professional labor
4. Semi-professional labor
5. Technical labor
6. Managerial labor
7. Clerical labor
8. Sales labor
9. Transport labor
10. Services labor
11. Farm labor
12. Artisanal labor
13. Production labor
14. Manual labor
15. 'Not classifiable' labor

The Water CGE model is relatively detailed on the household level. It incorporates eleven household types (Table 4). These households are distinguished by race[3], and by income group. The lowest third of the income spectrum (households with income less than 8,000 Rand per annum) is classified as 'poor', the middle third (household incomes between 8,000 and 30,000 Rand per annum) is describes 'medium' households, and the upper third (household incomes higher than 30,000 Rand per annum) is classified as rich households. 'Urban' African households are grouped together with African households living in metropolitan/semi-urban areas (such as for instance, what is commonly referred to as 'townships'). It should also be pointed out, that for the purposes of this model, poor and medium White households living in rural areas are also grouped together.[4]

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[3] In the regional SAM of the Olifantsriver Watershed, only the predominant racial groups (Africans and Whites) are used. Coloreds and Asians constitute only 0.9 percent of the total population of the Watershed, and have therefore been excluded.

[4] This was necessary, because the total number of poor, rural white households is insignificantly small.

Table 4: Household types

1. African, rural and poor households
2. African, rural and medium households
3. African, rural and rich households

4. African, urban and poor households
5. African, urban and medium households
6. African, urban and rich households
7. White, rural, poor and medium households
8. White, rural and rich households
9. White, urban and poor households

10. White, urban and medium households
11. White, urban and rich households

The rest of the Water CGE model is relatively less detailed as far as other institutions are concerned. There is one enterprise sector and one government sector. Since the Water CGE model is regional, it can distinguish between interregional (outside the region, but still within South Africa) and international (outside South Africa) trade. For the sake of simplicity, however, the two components of trade are summed together. Savings (and investments) by all institutional actors of the model (that is, households, enterprises, and the government sector) are captured by the model's capital account.

The indices used in the equations are:

i	Economic sectors listed in Table 2 (Note: j is an alias for i).
ie	Economic sectors that produce export goods
im	Economic sectors that use import goods
f	Factor inputs (see Table 3) comprised of subsets 'labor', 'capital' and 'law' (land-water aggregate)
sff	Subfactors associated with 'law', the land-water aggregate (see Table 3)
hh	Household types (see Table 4)
Firm	Enterprise
Govt	Government sector
ROR	Rest of region

Model assumptions

The Water CGE model is formulated as a static model. Its solution is a price vector, which equates all supplies and demands, and is found instantaneously, without price adjustments.

The Water CGE model assumes that the region's import and export prices are determined by world prices. This assumption is borrowed from international trade theory, and is commonly referred to as the 'small-country assumption'. When the share of a country in the world market is very small, and when users do not differentiate products by country or region of origin, a country is like a small firm in a competitive market: it is a price taker and cannot affect the terms at which it trades. It can reasonably be assumed that most sectoral exports of a given region face perfectly elastic demand curves at fixed prices. In most cases, it is appropriate to assume that only a few - if any - exports of a region have downward-sloping demand curves. For the purposes of this regional study, it was assumed that all exports faced perfectly elastic export demand curves.

The Water CGE model also assumes that the productive sectors produce both tradable goods for the export market (E), and non-tradables for the domestic market (D). In standard analytic models, it is often convenient to assume that domestic and foreign goods are perfect substitutes for each other, i.e. that all goods are tradable. In applied models, however, this is not a realistic assumption, since it logically leads to the conclusion that, if the domestic economy does not have a comparative advantage in the production of a good, then the domestic demand for goods is satisfied exclusively through foreign markets, and never through domestic markets.

Expressed differently, assuming that D and E are perfect substitutes for one another leads analytically to the situation where there is complete sectoral specialization in a few goods, and no domestic production in the vast majority of other goods. It is obvious that this does not conform to the economic reality of two-way trade in most regions or countries. By assuming that E and D are imperfect substitutes for each other, the model gains a much more realistic dimension.

By the same reasoning, domestic goods D are also assumed to be imperfect substitutes for imports M in domestic consumption Q.[5] The relative demand for M and D depends on their relative prices, P^M and P^D, and the elasticity of substitution between the two commodities.

Equations in the Water CGE model

Quantity equations [6]

All ten production sectors in the model are assumed to use a combination of three major factors (labor L - which is divided into thirteen different labor skills, capital K, and a land-water aggregate LAW) to produce the composite good X (Equation 5.1). The production functions' shift (a^P_i) and share ($\alpha_{i,f}$) parameters, are determined in the calibration of the model, based on the data in the underlying SAM. The production functions' substitution elasticities (ρ_i^P) come from outside the model, and vary by sector.

The sectoral production functions have a nested structure (Figure 1). At the top level, sectoral output is a linear function of real value-added and intermediate inputs. Intermediate inputs are demanded as a fixed proportion of output (Equation 5.8). Real value-added is a CES function of the primary factors in the model: labor, capital and the land-water aggregate. The

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[5] This assumption is commonly referred to as the "Armington assumption".

land-water aggregate, in turn, is a linear aggregation of water and land (Equation 7). $\omega_{i,sff}$ are sectoral land and water coefficients.

Differentiating Equation 5.1 with respect to the factor inputs yields Equation 5.2 determining factor demand. It should be noted that the equation embodies a frequently used simplification. To be complete, the production function (Equation 5.1) should include *all* inputs as arguments: capital, labor, the land-water aggregate, and intermediate inputs. The factor demand conditions would then be written as:

$$\textit{Factor price} = \textit{Value of marginal revenue} = (1-t^x) * P^x * \partial X/\partial \textit{Factor}$$

where 'Factor' denotes the full set of factor inputs, *including* intermediate goods. In Equation 5.1, the production functions, however, are specified as functions of the primary factors only. Intermediate inputs are given in Equation 5.8, while Equation 5.2 shows the demand for primary factors in the following form:

$$\textit{Factor price} = \textit{Value of average revenue} = P^{VA} * \partial X/\partial \textit{Primary factor}$$

where P^{VA} is the value-added price, which is defined (Equation 6.5) net of both indirect taxes and intermediate input costs. This treatment - ie. as seen in Equation 5.2 - is equivalent to writing out a full set of nested production functions, and their corresponding derivatives.

As the factor demand equations are written in the model, they assume that the primary factors are paid the same *average* wage - regardless of sector. The model allows for wage rates to capital and labor to vary across economic sectors, by introducing a distortion variable (*WFDIST*). This variable measures the degree to which a given economic sector's marginal revenue product deviates from the average.

In Equation 5.2b, the land factor (or the land-water aggregate, to be more precise) receives an additional treatment that the other factor inputs do not, because the land-water aggregate has subfactors associated with it. The returns to land are determined as the sum of the returns to the subfactors, in this case, land and water. In other words, the price of land is made to equal the cost of the water and land used. This condition drives the model to a competitive equilibrium with no positive profits.

Table 5: Quantity equations

(5.1) $X_i = a^P{}_i * \sum_f (\alpha_{i,f} * FACTORS_{i,f}^{-\rho_i^P})^{-1/\rho_P}$

(5.2a) $WF_f * WFDIST_{i,f} = PVA_i * a_i^t * \dfrac{\partial X_i}{\partial FACTORS_{i,f}}$

(5.2b) $WF_{LAW} * WFDIST_{i,LAW} = \sum_{sff} \omega_{i,sff} * WFSUB_{sff}$

$$(5.3)\quad X_i = a^t{}_i\ [\gamma\ E_i^{\rho_i^t} + (1-\gamma_i)\ D_i^{\rho_i^t}]^{\frac{1}{\rho_i^t - 1}}$$

$$(5.4)\quad Q_i = a^c{}_i\ [\delta\ M_i^{\rho_i^c} + (1-\delta_i)\ D_i^{-\rho_i^c}]^{-\frac{1}{\rho_i^c}}$$

$$(5.5)\quad E_i = D_i\ [\frac{PD_i}{PE_i} * \frac{\gamma_i}{1-\gamma_i}]$$

$$(5.6)\quad M_i = D_i\ [\frac{PD_i}{PM_i} * \frac{\delta_i}{1-\delta_i}]$$

$$(5.7)\quad FSUB_{i,sff} = \omega_{i,\ sff} * FACTOR_{i,\ lw}$$

$$(5.8)\quad INTMED_i = \sum_i io_{i,j} * X_i$$

Equation 5.3 defines the domestic production possibility frontier (PPF), which gives the maximum achievable combinations of the export good E and the domestic good D. This PPF is assumed to be concave to the origin, and specified as a CET (constant elasticity of transformation) function. Equation 5.3's shift ($a^t{}_i$) and share ($\gamma_{i,f}$) parameters are determined in the calibration of the model, the transformation elasticity (ρ_i^t) is determined outside the model. Differentiating X (Equation 5.3) with respect to E and D, yields the export supply functions found in Equation 5.5.

Equation 5.4 defines the composite commodity Q, which is made up of the domestic good D and the import good M. As already mentioned - under the "Armington assumption" - D and M are imperfect substitutes of one another. Composite good Q is defined as a CES function of D and M. As in the case of Equation 5.3, the shift ($a^c{}_i$) and share ($\delta_{i,f}$) parameters are determined on the basis of the data in the underlying SAM, the substitution elasticity (ρ_i^c) comes from the outside, and varies by sector. Differentiating Q (Equation 5.4) with respect to M and D yields the import demand function as seen in Equation 5.6.

Price Equations

Equations 6.1 through 6.9 determine the formation of prices within the Water CGE model.

Equations 6.1 and 6.2 reflect the 'small country' assumption described earlier: the price of imports (PM) and the price of exports (PE) is determined by the (exogenous) world prices of imports (pwm) and exports (pwe), respectively. In the Water CGE model, the domestic price of imports is the import tariff inclusive world price multiplied by the exchange rate. The domestic price of exports is simply the world price of exports times the exchange rate.

Table 6: Price equations

$$(6.1)\quad PM_{im} = pwm_{im} * (1 + tm_{im}) * EXR$$

$$(6.2)\quad PE_{ie} = pwe_{ie} * EXR$$

$$(6.3)\quad PQ_i * Q_i = PD_i * D_i + PM_i * M_i$$

$$(6.4)\quad PX_i * X_i = PD_i * D_i + PE_i * E_i$$

$$(6.5)\quad PVA_i = PX_i * (1 - itax_i) - \Sigma_i\, io_{i,j} * PQ_i$$

$$(6.6)\quad PK_i = \Sigma_i\, PQ_i * imat_{i,j}$$

$$(6.7)\quad PINDEX = GDPVA \;/\; RGDP$$

Equations 6.3 and 6.4 determine the prices of Q and X, respectively. Q is a composite commodity made up of D and M; PQ is a function of PD and PM. Analogously, X is a composite of D and E, its price PX is a function of PD and PE.

Equation 6.5 defines the price of value-added (PVA) which is the price of output net of indirect taxes, minus the unit cost of intermediate inputs.

Equation 6.6 determines the price of capital, differentiated by economic sector i. This specification reflects the fact that different sectors have different composition of capital. The matrix *imat* captures the sectoral composition of capital, by sector of origin. In the case of the Water CGE model, the information required for this capital coefficient matrix was not available. It was therefore approximated using sectoral investment data.[7]

Equation 6.8 specifies a price index, which is defined as GDP (estimated at value-added prices), divided by real GDP. The index represents a price level against which all relative prices in the model are measured. It is necessary in CGE models to determine such a numeraire price, because the models only determine relative prices.

Income equations

Conceptually, factor (value-added) incomes are distributed - via institutions (such as firms, government and the "rest of the region" (ROR)) - back to the different classes of households. These income flows at various stages of the economic cycle are specified in the equations of Table 7. The notation used in the equations is as follows: the subscript denotes the *source* of an income flow, the superscript denotes the *destination* of the income flow. For example, the left hand side

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[7] The Water CGE is a static model, which generates savings, investment and demand for capital goods. Capital goods are not installed within the "snapshot" period of the model: investment is therefore to be understood as a demand category, with no effects on supply.

of Equation 7.3 shows the income generated by capital and the land-water aggregate that accrues to firms.

Table 7: Income equations

(7.1) $Y_f^F = \sum_i WF_f * WFDIST_{i,f} * FACTORS_{i,f}$

(7.2) $Y^F_{lw} = \sum_{sff,i} WFSUB_{sff} * FSUB_{sff,i}$

(7.3) $Y^{Firm}_{Capital,\ LAW} = \sum_{Capital,\ LAW} Y^F_{Capital,\ LAW}$

(7.4) $Y^{HH}_{Labor} = Y^F_{Labor} - FCTR_{Labor}^{ROR}$

(7.5) $FCTR_{Labor}^{ROR} = \psi_{Labor} * Y_{Labor}^F$

(7.6) $Y^{HH}_{Firm} = Y^{Firm} - Tax^{Govt}_{Firm} - Dividends^{ROR}$

(7.7) $Y^{HH} = \sum_{Labor} \Theta_{HH,Labor} Y^{HH}_{Labor} + \sum_{Firm} \Theta_{HH,Firm} Y_{Firm}^{HH}$
$+ Transfers^{HH}_{Govt} + Remittances^{HH}_{ROR}$

(7.8) $Transfers^{HH}_{Govt} = \xi^{HH}_{Govt} * Y^{HH}$

(7.9) $Remittances^{HH}_{ROR} = \nu^{HH}_{ROR} * Y^{HH}$

(7.10) $Tariff = \sum_{im} tm_{im} * M_{im} * pwm_{im} * EXR$

(7.11) $Indirect\ tax = \sum_i itax_i * PX_i * X_i$

(7.12) $Firm\ tax = \varepsilon^{Govt}_{Firm} * Y^{Firm}$

(7.13) $HH\ tax = \sum_{hh} \varpi_{HH} * Y^{HH}$

(7.14) $Govt\ revenue = Indirect\ tax + Tariff + Enterprise\ tax + HH\ tax$

(7.15) $HH\ savings = \sum_{hh} mps_{HH} * (1 - \varpi_{HH}) * Y^{HH}$

(7.16) $Govt\ savings = Govt\ revenue - \sum_i PQ_i * GD_i - \sum_i Transfers^{HH}_{Govt}$

(7.17) $Savings = HH\ savings + Govt\ savings + Foreign\ savings * EXR$

It is important in the income and expenditure equations to distinguish between parameters and variables: many of the variables in the income equations are set exogenously or determined by simple share or multiplier relationships, rather than through complex behavioural functions (as those seen in the quantity equations of Table 5).

Equation 7.1 defines factor incomes (accruing to the factors across economic sectors), which in turn is redistributed to firms, households, and ROR in Equations 7.3, 7.4 and 7.5. Again, the land-water aggregate is treated somewhat differently than the other factors (Equation 7.2), because of the subfactors associated with it.

Value-added accruing to capital and the land-water aggregate is paid out to firms first, before the firm redistributes it - after paying out taxes and extra-regional dividends - to households (Equation 7.3). Value-added accruing to the different labor categories is paid directly to the households - net of factor payments paid to ROR - without an intermediate institution involved (Equation 7.4). Since the Water CGE model is regional in nature, a proportion ${}_{Labo}$ of the total value-added accruing to labor is paid out to ROR (Equation 7.5).

Equation 7.7 determines total household income which is made up of income from wage labor, income received from firms in the form of dividends, income received from the government sector in the form of transfers, and finally - and in the case of rural South Africa - very importantly, household income received from other (extraregional) households in the form of remittances. The proportions of total income from wage labor and from firms paid out to individual household categories are denoted by $\theta_{HH,Labor}$ and $\theta_{HH,Firm}$, respectively.

Government transfers to households constitute a proportion $\xi^{HH}{}_{Govt}$ of the household's total income (Equation 7.8); remittances to households from ROR are a proportion $\nu^{HH}{}_{ROR}$ of household income (Equation 7.9).

Equations 7.10, 7.11, 7.12 and 7.13, define government tariffs, indirect taxes, taxes from firms and households, respectively. Revenues from tariffs are calculated as a share t_m of the import bill, calculated at world prices and subsequently converted into domestic prices. Indirect taxes are again a fixed share $itax_i$ of the value of domestic production. Enterprise taxes are a proportion ϵ_{Firm} of firm income; household taxes are a proportion ϖ_{HH} of household income. Government revenue, specified in Equation 7.14, is then simply defined as the sum of government tariffs, indirect taxes, firm and household taxes.

Total savings in the economy (Equation 7.17) are defined as the sum of household savings (Equation 7.15), government savings (Equation 7.16) and foreign savings. Households are assumed to save fixed proportions mps_{HH} of their disposable incomes $(1-\varpi_{HH}) * Y^{HH}$. Government savings are defined as the difference between its revenues and outlays on government consumption and transfers to households; it is possible that government savings are negative, hence representing a government deficit.

Expenditure equations

The equations determining expenditures in Table 8 complete the circular flow of income in the economy.

Individual household categories consume a (fixed) proportion $cles_{i,HH}$ of their disposable incomes (net of savings and taxes) on good i. Summed up over all households, Equation 8.1 determines private (household) consumption over sector i. Equation 8.2 defines total private consumption, summed over all sectors.

Equation 8.3 defines government consumption on good i, which is a fixed proportion $\varphi_{i,Govt}$ of total government consumption. Equation 8.4 requires that total government expenditures equal the sum of total government consumption (summed over all goods/sectors i), transfers to households and government savings (or deficits).

Table 8: Expenditure equations

(8.1) $PQ_i * CD_i = \sum_{hh} cles_{i,HH} * (1-mps_{HH}) * (1-\varpi_{hh}) * Y^{HH}$

(8.2) $TCON = \sum_i PQ_i * CD_i$

(8.3) $GD_i = \varphi_{i,Govt} * \sum_i GD_i$

(8.4) $Govt\ revenue = \sum_i PQ_i * GD_i + HH\ Transfers + Govt\ savings$

(8.5) $Investment = \sum_i PQ_i * (ID_i + Inventory\ changes_i)$

(8.6) $GDPVA = \sum_i PVA_i * X_i + Indirect\ tax + Tariff$

(8.7) $RGDP = \sum_i CD_i + ID_i + Inventory\ changes_i + GD_i + \sum_{ie} E_{ie} + \sum_{im} (1-tmreal_{im}) * M_{im}$

Investment in the Water CGE model is simply defined as the value of sectoral investment (ID_i) and the value of changes in sectoral inventories (Equation 8.5).

Equations 8.6 and 8.7 define nominal and real GDP, respectively. These two items are needed to calculate the numéraire price index defined in Equation 8.8. Nominal GDP is estimated from the value added side. Since PVA is defined as the 'net' price (output price net of indirect taxes minus the price of intermediate inputs, net of import tariffs), the value of indirect taxes and tariffs is added to nominal value-added. Real GDP is defined from the expenditure side. In the calculation of RGDP, the value of imports does not include tariffs.

Market-clearing conditions and material balance equations

Equilibrium in the Water CGE is achieved endogenously, by adjustment of both commodity and factor prices. The equations listed in Table 9 specify the equilibrium conditions of the Water CGE model. Equation 9.1 requires that in equilibrium, sectoral supply (Qi) equals sectoral demand, the latter being the sum of sectoral intermediate input demand, sectoral private consumption, sectoral government consumption, and sectoral investment, including changes in sectoral inventories.

Equations 9.2 and 9.3 are known as 'material balance equations' because they specify that the demand for factors and subfactors, respectively, may not exceed their fixed supply. Equation 9.2 embodies the assumptions of full employment of the factor stocks, and full mobility between the sectors. As an inequality, Equation 9.3 allows for less than full employment of either of the subfactors; in other words, it allows some of the subfactor to be left redundant.

Table 9: Market clearing equations

$$(9.1)\ Q_i = INTMED_i + Private\ consumption\ (=CD_i) + Govt\ consumption\ (=GD_i) + Investment_i$$

$$(9.2)\ \sum_i FACTORS_{i,f} = Factor\ supply_f$$

$$(9.3)\ \sum_i FSUB_{i,sff} \leq Subfactor\ supply_{sff}$$

$$(9.4)\ Foreign\ savings = pwm_{im} * M_{im} - pwe_{ie} * E_{ie} - HH\ remittances_{ROR} + Dividends^{ROR} * EXR - FCTR_{Labor}^{ROR} * EXR$$

$$(9.5)\ Savings = Investment + WALRAS$$

Equation 9.4 defines the current account balance. It is equal to the value of all "inflows" into the economy, minus the value of all "outflows". More specifically, FSAV is defined as the value of imports and remittances into the region, minus the value of exports, dividends and factor payments paid abroad. According to accounting conventions, remittances into the region are considered to be a regional liability and conversely, a ROR asset; dividends and factor payments into ROR are considered to be regional assets and ROR liabilities. The last equation in Table 9, Equation 9.5, specifies that aggregate savings equal aggregate investment.

Macroeconomic closure rules

In CGE models, all accounts must specify the entire circular flow of funds in the system - there can be no leakages from the system. The Water CGE model is specified in terms of current flows and flow-equilibrium conditions only (such as Equations 9.1 and 9.2, for example) - there are no assets and assets markets. In order to achieve balance or equilibrium where macroeconomic variables in the model are concerned, certain macro 'closure' rules need to be applied. For instance, since there may be no leakages out of the system represented by the CGE model, the model must reconcile aggregate savings and aggregate investment (Equation 9.5)

This reconciliation of savings and investment is referred to as the 'closure' problem because it involves the 'closing' of one of the model's macro-accounts. Beside the savings-investment account, the model must also balance the foreign account (balance of trade, as defined in Equation 9.4) and the government account (Equation 8.4).

In order to satisfy balance in these accounts, it is necessary to choose the variables that will adjust freely to achieve equilibrium, and constrain other variables by fixing them exogenously. For example, in the (regional) Water CGE, the exchange rate (*ER*) is fixed exogenously[8]; the corresponding variable *FSAV* - the balance of trade variable - is therefore allowed to equilibrate in the model.

The Water CGE model is considered to be "savings-driven": savings rates of the institutions (households and the public sector) are determined exogenously, thereby determining aggregate savings. By the savings-investment identity, aggregate investment ($S \equiv I$) is subsequently determined.

Government tax rates are set exogenously, so that government revenue is determined exogenously. Government savings/deficit is determined residually, as the difference between government revenue and government expenditures.

Endogenous and exogenous variables

The following section lists all endogenous and exogenous variables of the Water CGE model. It should be noted that according to the closure rules chosen, the following pairs of variables alternate in their endogeneity and exogeneity: EXR vs. FSAV, FS vs. WF, FSUB vs. WFSUB, and SAVINGS vs. INVESTMENT. For example, if EXR (the exchange rate) is fixed exogenously, then FSAV must be an endogenously equilibrating variable. The same applies to the other pairs.

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[8] The exchange rate *ER* denotes the relative price between tradables (E and M) and non-tradables (D).

Table 10: Endogenous and exogenous variables in the Water CGE model

Endogenous Variables

Quantity variables (7):

X_i	Aggregate output
$FACTORS_{i,f}$	Factor demand by activity
$FSUB_{i,sff}$	Subfactor demand by activity
Q_i	Composite good
E_i	Export good
M_i	Import good
D_i	Domestic good

Relative price variables (11):

PM_i	Price of import good M
PE_i	Price of export good E
PD_i	Price of domestic good D
PQ_i	Price of composite good Q
PX_i	Price of output X
PVA_i	Price of value-added
PK_i	Price of capital
WF_f	Factor price
$WFSUB_{sff}$	Subfactor price
$WFDIST_{i,f}$	Factor market distortion variable
PINDEX	GDP deflator

Income variables (15) :

Y^{F}_{f}	Factor income
Y^{F}_{Land}	Land income
$Y^{Firm}_{K,L+W}$	Firm income from non-labor value-added
Y^{HH}_{Labor}	Factor (labor) income distributed to households
$FCTR^{ROR}_{Labor}$	Factor (labor) income distributed to ROR
Y^{HH}_{Firm}	Household income received from firms
Y^{HH}	Household income
Tariff	Government receipts of tariffs (on final imports)
Indirect tax	Government receipts of indirect taxes (on intermediate imports)
HH tax	Government receipts of taxes paid by households
Firmtax	Government receipts of taxes paid by firms
HH savings	Household savings
Govt revenue	Government revenue
Govt savings	Government savings

Savings	Total savings

Expenditure variables (7):

CD_i	Private (household) consumption
TCON	Total nominal consumption
GD_i	Public (government) consumption
Investment	Total investment
Govt revenue	Government revenue
GDPVA	Gross domestic product at value-added prices
RGDP	Real gross domestic product

Market clearing variables (5):

$INTMED_i$	Intermediate goods
FS_f	Factor supply
$FSUB_f$	Subfactor supply
FSAV	Foreign savings
WALRAS	Walras variable

Exogenous Variables

Relative price variables:

EXR	Exchange rate
pwe_i	World price of exports
pwm_i	World price of imports
PINDCON	Consumer price index

Income variables:

$Transfers^{HH}_{Govt}$	Household transfers from government
$Remittances^{HH}_{ROR}$	Household remittances from ROR

Parameters

a_i^P	Production (CES) function shift parameter
$\alpha_{i,f}$	Production (CES) function share parameter
ρ_i^p	Production(CES) function substitution elasticity
$\omega_{i,sff}$	Subfactor use coefficient
a_i^t	Transformation (CET) function shift parameter
$\gamma_{i,f}$	Transformation (CET) function share parameter

ρ_i^t	Transformation (CET) function substitution elasticity
a_i^c	Armington (CES) function shift parameter
$\delta_{i,f}$	Armington (CES) function share parameter
ρ_i^c	Armington (CES) function substitution elasticity
$io_{i,j}$	Input-output coefficient matrix
tm_{im}	Import tariff rate
$itax_i$	Indirect tax rate
$imat_{i,j}$	Investment composition matrix
ψ_{Labor}	Labor value-added shares
$\Xi_{HH,Labor}$	Household wage labor shares
$\Xi_{HH,Firm}$	Household dividend shares
ξ^{HH}_{Govt}	Household government transfer shares
ν^{HH}_{ROR}	Household remittance shares
$\varepsilon^{Govt}_{Firm}$	Enterprise tax rate
ϖ_{HH}	Household tax rates
mps_{HH}	Household savings rates
$cles_{i,HH}$	Household consumption shares
$\varphi_{i,Govt}$	Government consumption shares
$tmreal_{im}$	Real tariff rates

The Water CGE model's solution

The Water CGE model has altogether 46 blocks of equations and 45 blocks of endogenous variables. The equilibrium conditions - as specified in the equations of Table 9 - however, are not all independent. According to Walras' Law, any one of these equilibrium conditions can be dropped, and the resulting model is square and fully determined, with a unique solution.

A typical neo-classical CGE simulation will generally have a unique solution that satisfies all the non-linear first-order conditions with all prices strictly positive, and all constraints satisfied as inequalities. In the Water CGE model, however, the first-order conditions for the land and water constraints, are summarized in the linear cost functions in Equation 5.2b. The problem is, however, that there is an infinite number of solutions that satisfy the cost functions in Equation 5.2b (for the subfactors, land and water), and the two inequality constraints in Equation 5.3.

If the Water CGE model is solved as a non-linear program, with a solver such as MINOS or CONOPT, then it is necessary to specify an explicit maximand to ensure that there is a solution in which at least one of the inequality constraints is binding, *i.e.* that the economy, in fact, is operating on the production possibility frontier.

The addition of the maximand completes the activity-analysis specification of the model for the use of land and water. A zero price for either of the subfactors is possible, but both the price of land and water cannot be zero, since Equation 5.2a does not allow for a zero rental for the land-water aggregate at the top level of the production function.

Since the Water CGE model intends to simulate the workings of a competitive economy, with zero profits. Equation 5.2b. specifies explicitly that the price of the land-water aggregate (WF_{LAW_j}) must be exactly equal to the sum of the prices of its components, that is, the prices of land and water used. The maximand chosen in this case, consumer welfare. In a market economy, its maximization will generate a profit-maximizing market equilibrium.

Since the model is square and is a mixture of equality and inequality constraints, it is also possible to solve the Water CGE as a mixed-complementarity problem (MCP), using solvers such as PATH or MILES. The inequalities in the system of equations need to be complemented with the relevant complementary slackness conditions. If the model is formulated as an MCP, it does not require a maximand or minimand.

The model's 'What if?' questions

Once the base Water CGE model is generated, it is possible to ask a multitude of water allocation-related questions, which are then modeled as 'shocks' to the base Water CGE model. The subsequent shocked model solution generates information about water-related, counter-factual ***'What if?'*** questions.

For this paper, the following *'What if?'* questions were asked: First, ***what if*** South Africa were to institute a market for water, and charge a scarcity price for water used?
What would the economy-wide effects be, if the economic sectors could no longer use water as if it were an abundant resource? What would the effects be, if an appropriate incentive framework - which would include the implementation of water tariffs that more closely approach marginal costs - were developed? Second, ***what if*** current water and/or land policies (*i.e.* where land is associated with its share of water) that have historically favored commercial agriculture were altered to favor 'homeland' agriculture? What would the economy-wide effects of such a re-orientation be? Would the direct benefits that accrue to the 'homeland' agricultural sector through a policy re-orientation outweigh the indirect costs from burdening the commercial agricultural sector with added economic pressures? The main hypotheses that guide the analysis can maybe better understood if they are viewed as the anticipated answers to the "What if?" questions that were detailed above.

Simulation 1: The effects of water curtailment or the demand for water

To explore the importance of water availability in the economy of the Olifantsriver Watershed, a series of experiments was conducted in order to trace out the demand for water. It should be reiterated that in this Water CGE model, *both the agricultural and non-agricultural uses of water* are included. This specification with both agricultural and non-agricultural water use stands in contrast to other water-related CGE models, such as Robinson and Gelhar (1995) and Löfgren (1995), who consider only agricultural uses of water.

It is important to point out that this series of experiments should be understood not so much as a predictor of sectoral water uses under periods of water shortage, but rather as a guide in identifying where the strains are within the system, vis-a-vis water availability.

In this series of five experiments, the aggregate supply of water was progressively cut in increments of 15 percent, until the aggregate water supply was reduced by 75 percent.

Figure 2 shows the demand for water. This demand curve is a general equilibrium demand curve: with a shock to the economy, such as a water cut, the system is allowed to fully adjust - with changes recorded in all sectors' supplies, demands, and prices (both of the factors and commodities). The demand curve is quite steep, with an arc price elasticity that ranges from 0.16 to 0.8.

As the aggregate supply of water is reduced, the existing system in the base - complete with all built-in distortions such as tariffs- seeks to maintain production - even in high water-using sectors, thereby generating a relatively inelastic demand for water.

The simulated value of the land-water aggregate arises from its marginal productivity in production and incorporates both the value of raw land and the water right associated with land ownership. (Figure 3 shows the demand for the land-water aggregate as water is cut). The model simulations can be used to allocate the total value of the land-water aggregate between raw land and water, which is unobservable since there are no separate markets for raw land and water. (In the Water CGE, the price of the land-water aggregate is fixed in closure, so the simulated price is fixed, but the solution yields the prices of raw land and raw water.)

As Figure 4 shows, in the (distorted) base, the price of land is about 50 Rand per hectare, while that of water is approximately 0.03 cents per cubic meter.[9] As the water aggregate supply is reduced, the price of land falls, while the price of water rises. With experiment number 4, which is a 60 percent cut in the aggregate water supply, the land constraint is no longer binding, and as a consequence, land is taken out of production altogether. As the land constraint relaxes, its price becomes zero. At this point, the price of the top level land-water aggregate, is determined solely by the price of water. In other words, as the land constraint is no longer binding, the value of the land-water aggregate depends exclusively on the fact that land use carries with it the right to water use. Figure 4 illustrates the relationship between the price of land and the price of water.

Figures 5 through 9 show the sectoral changes in both water and land demand, respectively, as the aggregate water supply of the economy is reduced. In the first water cut (15 percent reduction), horticultural agriculture, mining, manufacturing, the electricity and water generating and construction sectors, decrease their use of water by 25, 23, 31, 21 and 2 percent respectively. At the same time, field crop agriculture, livestock agriculture, 'homeland'

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[9] 50 Rand per hectare is approximately the rental rate of maize land in the 'homelands'; on government sponsored irrigation schemes, the price of water varies between 0.01 and 0.05 Rand per cubic meter.

agriculture and the service sector, increase their water use by 2, 5, 7, and 5 percent, respectively. These adjustments can be explained by the relative water efficiency of the livestock and 'homeland' agricultural sectors, and the service sector.

As water becomes more scarce with the subsequent cuts in water availability, field crop agriculture adjusts dramatically, by reducing its water use in the last experiment by 75 percent compared to the base (Table 11). Horticultural production is the most water intensive sector within the agricultural sector, and as such, reduces its water demand by 90 percent. 'Homeland' agriculture is a very land-water intensive sector; as water becomes an expensive factor input in the face of drastic water cuts, it reduces its demand by over 50 percent. Livestock agriculture is land- rather than water-intensive, and in the initial cuts, demands more water, before it, too, cuts back its demand for water. The non-agricultural sectors cut back their demand for water as drastically as the non-agricultural sectors when water availability is reduced by 75 percent.

More interesting to note, however, are the changes in water demand after the initial cuts in water supply, as seen in Table 11. Until water is reduced by 60 percent, 'homeland' agriculture increases its demand for water by 38 percent, before it cuts back. Similarly, the service sector demand 19 percent more water as aggregate water is cut by 60 percent, and only reduces its demand in the last (and very drastic) experiment.

These sectoral water demand curves reflect the combination of the sectors' land-water (aggregate) intensity, and their water versus land (subfactor) intensity. Although livestock agriculture is assumed to be land-water intensive, its water to land coefficient is low, and therefore the sector is not forced to drastically substitute away from the increasingly expensive water resource. Manufacturing, on the other hand, is assumed not to be land-water intensive, but does have a high water-land ratio. In the face of water cuts - even relatively mild ones - is forced to substitute away from water.

As was shown earlier, these results are highly dependant on the assumptions underlying factor and subfactor demands and prices, as they are captured in the SAM, when they are coupled with experiments such as drastic cuts in aggregate water availability.

The effects of water cuts on factor employment are relatively mild. With a water cut of 60 percent compared to the base model, most factor wages decrease by less than one percent. The notable exception, however, is farm labor, which experiences an 8 percent decline in both its wage and factor income. This result indicates that when water cuts are instituted and water prices rise, there is considerable scope for appropriate technological change due to substitution between factors of production.

Changes in most economy-wide indicators - like GDP - are relatively small, even in the face of rather severe water cuts. Agricultural output, however, declines by nearly 10 percent as water is cut by 60 percent. As the largest water user, the agricultural sector is most hurt by water curtailment policies (Tables 12 to 17).

It must be remembered that in this series of simulations, distortions in the economy are left untouched. Therefore, both the base solution of the model and the solutions to the water cut experiments, incorporate these market distortions. This helps to explain, why field crop agriculture continues to perform relatively well when aggregate water supplies are cut, despite the fact that it is the largest user of both land and water resources. The tariff rate on its imports is assumed to be 7 percent, which is relatively low compared to some of the other sectors.

Simulation 2: The effects of land and water reform

As Table 18 shows, the base Water CGE model assumes that 'homeland' agriculture occupies approximately 3 percent of the total watershed's land area. This stands in marked contrast to field crop agriculture and livestock agriculture, which occupy 72 and 13 percent, respectively (i.e. 85 percent of the total watershed area).

In order to simulate the effects of land and water reform in the watershed, the following three sets of experiments were conducted: in the first series, total land availability was cut from its initial value of 4.24 million hectares in five successive increments of 5 percent, until land availability was reduced by 25 percent. With land being predominantly under field crop and livestock agriculture, the land cuts affect these two sectors more than any of the other economic sectors. Additionally, in the first round of simulations, the 'homeland' agricultural sector was given an exogenous productivity boost. In the second round of experiments, water reform - rather than land reform - was simulated: total water availability was reduced in five successive experiments by 5 percent, until it was 25 percent of the base model. Again, it was assumed that 'homeland' agriculture benefitted from land-water productivity enhancing technology. In the third set of experiments, water availability is cut, and 'homeland' agriculture was assumed to benefit from a productivity boost - but of a different kind than in the first and second set of experiments.

As Table 19 shows the (rental) price of land and the price of water in the Water CGE model have been assumed to be uniform across sectors. (A price of land of 50 Rand per hectare is the estimated rental rate for land used for maize cultivation in the 'homelands'; this figure represents approximately one-fifth of the value of total gross income stemming from maize cultivation on one hectare). Although this greatly simplifies the model specification, it is clear that this does not conform to the reality of rural South Africa. Quality differences in land and water resources are enormous, and it is undeniable that land and water resources in the 'homeland' areas are by far inferior to those used by the commercial agricultural sector, for instance.

In order to simulate not just a land reform which reduces the availability of land for field crop and livestock agriculture and creates a scarcity price for the land (subfactor), but also to simulate improved access to better quality land and water resources, the three sets of experiments simulate (exogenous) increases in productivity growth in the 'homeland' agricultural sector.

More specifically, in the first set of experiments, the shift parameter a^p_i of the sector's production function (Equation 5.1) is increased successively by 5 percent, until it is 25 percent higher than the base value. In the second set of experiments, it is assumed that 'homeland' agriculture enjoys land-water augmenting technical progress: the productivity of the sector's land-water aggregate is increased by a modest 1 percent. In the third set of experiments, it is assumed that the 'homeland' agricultural sector has the same input-output coefficients as field crop agriculture.

The results from the first set of experiments (5 percent land cuts, 5 percent incremental increases in technological enhancement) are quite dramatic. Even though 'homeland' agriculture is assumed to be land-intensive, when given a productivity enhancing technology boost, its output still nearly triples relative to its base value (Table 20). Domestic sales and exports rise by 130 and 317 percent, respectively.

As expected, field crop agriculture - as a both a relatively land-intensive sector and a big user of land - suffers the most in this experiment of land cuts and 'homeland' productivity increases: its output falls by nearly a third by the time land is cut by 25 percent. The livestock sector does not fare as poorly, but it - as a land-intensive sector - suffers from land cuts, and cannot increase its output.

Horticulture, on the other hand, is a water-intensive sector, and benefits from a situation in which land becomes a relatively more expensive factor: its output increases by 7 percent as land is cut by 25 percent. Despite the simulation which favors 'homeland' agriculture, horticultural production still enjoys output and export growth. The non-agricultural sectors are not as severely affected, since they are not assumed to be land-intensive sectors.

Sectoral water (and land) demand changes are large, as Table 20 shows: when land is cut by 25 percent and productivity of 'homeland' agriculture is increased by 25 percent, water demanded by 'homeland' agriculture increases by 182 percent. The land-intensive agricultural sectors, cut back on land and hence, on water: field crop agriculture's demand for water falls by 40 percent, livestock agriculture's demand for water falls by 24 percent. Among the non-agricultural sectors water demand increases for the relatively more water-intensive sectors (manufacturing and electricity), and decreases for the relatively more land-intensive sectors (transport and construction).

Even the second experiment, which assumes a much smaller productivity boost for 'homeland' agriculture, still yields very favorable results for the sector, as Table 20 shows. This time when *water* is cut by 25 percent, and land-water productivity (the neutral technological change assumed in the first set of experiments is replaced by land-water enhancing technological change in this second set) is increased by 5 percent, 'homeland' agriculture is still able to increase its production by 23 percent and its exports by 24 percent, relative to the base.

The other agricultural and non-agricultural sectors do not attain results that are nearly as large in magnitude. And since this time water is cut, it is the relatively more water-intensive sectors that suffer. Output in the horticultural sector falls by 12 percent, while output in field crop agriculture and livestock agriculture increase by 2 and 3 percent, respectively.

In the third series of experiments, 'homeland' agriculture is assumed to use the same technology as field crop agriculture. This is achieved by replacing the input-output coefficients of 'homeland' agriculture in the model with the same input-output coefficient values of field crop agriculture.

Due to initial data limitations (the original agricultural data was not disaggregated), it was not possible to be very precise in estimating the different agricultural subsectors' input-output coefficients. The differences in the IO coefficients between field crop and 'homeland' agriculture are not as large as one would expect. For example, inputs from the manufacturing sector - such as fertilizer, for example - are assumed to be approximately 20 percent less than in 'homeland' agriculture. Despite this and other similar assumptions which would tend to reduce the gap that actually exists between 'homeland' and field crop agriculture, the original data do - albeit insufficiently - reflect the 'homeland' agricultural sector's higher cost structure (for transport, for instance, per unit of output) and its lower state of technology (seen in its use of inputs from the manufacturing and service sectors).

Even though the initial data would underestimate the impact of giving 'homeland' agriculture the same technology as field crop agriculture, Table 20 shows, that 'homeland' agriculture enjoys the largest (positive) changes, even when the economy is shocked by water reform policies. 'Homeland' agriculture's output increases by 18 percent, domestic sales by 14 and exports by 18 percent. As in the previous set of experiments, horticulture is the sector that suffers most, when water is cut, while the non-agricultural sectors experience negligible changes in their outputs and exports.

Table 21 shows that both real and nominal GDP decreases in the three sets of land and water reform experiments. Agricultural output, too, declines in all three sets. But the figures in Table 21 do show that *how* land and/or water reform is instituted will influence certain aggregate results. The percentage differences between the three sets are not large, but are not insignificant in monetary units. The process by which land-water income (and its owners) is affected, has important political implications that can profoundly influence reform policies.

Examination of the model hypotheses

Now, the model hypotheses that were presented at the beginning of this paper can be analyzed:

Hypothesis: Water, as a factor input, will be allocated away from commercial, large-scale agriculture, to the other economic sectors.

This is only partly true in the Water CGE model as it currently formulated. Commercial (field crop) agriculture is assumed to have a fairly low water-land coefficient; when the economy is shocked, due to water cuts, for example, it is the more water-intensive sectors (like horticultural agriculture) that reduce their water demand. The hypothesis is true for some of the non-agricultural sectors, which are assumed to have very low water intensities (like the service sector): when the system is mildly shocked, their water demand increases, because they use water relatively more efficiently.

The hypothesis implicitly assumes that commercial agriculture has a higher water-land ratio than the other sectors, so that when water becomes scarce, it will substitute away from the increasingly expensive water factor. However, as the data show, in the case of the Olifantsriver Catchment, it cannot be assumed that all non-agricultural users are characterized by low water intensities. Indeed, if the numbers concerning water use are reliable, then sectors like manufacturing have very high water-land intensities.

Therefore, it appears that the hypothesis will be true when high-value producing sectors, like manufacturing, reduce their water intensities.

Hypothesis: Within the agricultural sector - even without preferential policies - water will be allocated away from large-scale, commercial farms and allocated to small-scale farms.

This hypothesis is again only partly true, for the same reasons that were given above: the initial assumptions concerning water use, give field crop and livestock agriculture relatively low water intensities. In the face of policies that make water more scarce, these sectors do not suffer as much as is indicated by the hypothesis.

Hypothesis: Sectoral employment will shift in accordance with water allocations: away from agriculture to other economic sectors that use water more productively.

This hypothesis is wrong, because it presumes again that agriculture is more water intensive than the non-agricultural sectors.

Hypothesis: Household incomes for poorer households will increase.

The Water CGE model in its current specification is not well suited to examine this hypothesis. Since it assumes full factor employment, changes to household incomes and other aggregate variables are small, and are therefore not useful in examining the hypothesis.

Hypothesis: Agriculture will be the overall 'loser' in the regional economy, but given the social and financial gains achieved in the other economic sectors, regional gross domestic product (GDP) will not be seriously affected.

The hypothesis is true, given the assumptions. Since agriculture is the largest consumer of water, when water becomes more expensive, output in the agricultural sector falls. GDP is not seriously affected, but mainly because of the Water CGE's specification of full employment.

Policy recommendations and conclusions

According to existing South African law, water rights are firmly and inextricably linked to private land rights. The Water Act of 1956 specifically rules that all water that is physically linked with land held in private ownership is considered to be private water. The legislation therefore creates a very strong incentive for private landowners to create their own bodies of water - through the damming of rivers, for instance - on their private landholdings.

While these practices are both socio-economically and environmentally disadvantageous, they are not altogether incompatible with the existence of alternative water use arrangements, such as water markets, for instance. However, since it is also forbidden in South Africa to either convey or dispose of private water through sale or lease arrangements without ministerial approval, water markets have not evolved systematically. (As mentioned earlier, informal sales of water do occur, but these are considered to be illegal, and therefore not known of, other than through anecdotal reports).

The Water CGE model shows that land (or rather the land-water aggregate) becomes economically virtually useless after a certain point of water scarcity. At that point, the value of land in the land-water aggregate becomes nil, and is determined solely by the value of the water that is associated with the land.

This specific formulation makes the Water CGE model very useful for policy purposes, because it helps to conceptually separate water from land rights. The model allows the separate evaluation of subfactors prices; in other words, the model allows the prices that are associated with the water and land rights to be determined individually. If South Africa were to effect policies that would move the country towards improved marketability of water resources, it would be crucially important to separate land and water rights, especially if land continues to be held in enormous private tracts, as it is now.

With historically established incentives and water rights still in place, water is still being used as if it were an abundant - rather than a scarce - resource. Water still does not have the scarcity price that it should carry for efficient water management, and as a result, most economic sectors use water inefficiently. As in most countries, agriculture in South Africa is the largest user of water. However, other economic sectors in South Africa, which are not conventionally considered to be large users of water - such as manufacturing, for instance - demand rather sizeable amounts of water. This tendency towards economy-wide water inefficiency emphasizes how inadequate the economic incentives vis-a-vis water really are.

The specification underlying the Water CGE model does not allow any of the economic sectors to stop production altogether. In reality, however, it is altogether possible that, as water scarcity becomes a severely constraining characteristic of the South African economy, water-intensive sectors may be forced to cease production - certainly, if they are unable to adopt new, water-saving technologies.

The Water CGE model simulations show that when in fact a meaningful scarcity price for water is charged, that those sectors which use water relatively *less* intensively are considerably less disadvantaged compared to those sectors that use water *more* intensively. As the model simulations suggest, even very small changes in the (scarcity) price of water can effect very large changes, and re-orient the economy to more efficient allocations.

In the Water CGE model of the Olifantsriver Catchment, homeland agriculture has a low water intensity. When a real scarcity price for water is charged, it initially fares much better than any of the other economic sectors. It must be pointed out, however, that these results say nothing of domestic water consumption. If scarcity prices for water are charged, it may be necessary to subsidize poor households, in order to defray the increased costs of water.

Another set of simulations from the Water CGE show that relatively small changes to the productivity of homeland agriculture can produce - often staggeringly - positive effects in terms of output, exports and other variables. This result should suggest to South African policymakers that possibly small investments that would improve either overall productivity in the (former) homelands, or would directly target land-water related productivity, would effect large and positive changes in formerly neglected areas. Or in colloquial terms, it appears that South Africa can expect "a big bang for its buck".

It is even possible that the model results concerning homeland agriculture are actually underestimates. For instance, the SAM on which the Water CGE is based, does not specifically account for the inferior quality of land and water resources that homeland agriculture must use. Additionally, certain parameters - such as the factor substitution parameters - that were used to model homeland agriculture are probably overly optimistic, and underestimate the tremendous difficulties that these productive units face. Any policies that directly improve the factor substitution possibilities for production in the former homelands would - as the model suggests - create large and positive changes for these disadvantaged groups.

The broad policy implications from this analysis are that South Africa's policymakers should attach top priority to measures that promise to raise long-run productivity growth in all economic sectors, especially vis-a-vis water. If the country desires to address inequities that have evolved historically and continue to curtail the productivity of economic units operating in the former homelands, the results for the Water CGE model suggest that even relatively small, but directly targeted investments to these units would considerably improve their economic situation.

Even though considerable efforts to improve the quality of data have lately been made - notably, in such endeavors as the SALDRU survey - the quality of the data describing the subsistence and informal sector side of the economy remains poor. In a model such as the Water CGE and other models that are concerned with environmental factors such as water and land, it will be especially important to better capture especially the production structure of economic sectors in the former homelands. The SALDRU data set has given researchers considerable new insight into consumption and expenditure patterns of households in South Africa, especially the poorer and rural households that have been historically less well understood and researched. However, detailed production-side information - such as homeland crop budgets - are still either lacking or unreliable.

A number of important issues that are currently occupying South African policy makers have been left out, but are extremely important and need to be included in any further research concerning water allocation and management in South Africa. Once again, it is imperative that data that would help elucidate these research questions becomes available.

Forestry and environmental water: In many parts of South Africa - including in the Olifantsriver Watershed - the commercial forestry sector is an important user of water. The tree species grown in the large-scale forestry plantations in the upper elevations of the Eastern Transvaal are particularly thirsty, and are in large part blamed for water shortages in the lower elevations (Fuggle and Rabie, 1992). Currently, policymakers are adamant that the forestry industry is in great part responsible for severe reductions in water levels in the lower parts of river catchments.

Unfortunately, because relevant data on the forestry sector was not available, it was not included in the SAM and subsequent Water CGE model. This is very unfortunate, since the currently South African policymakers are seriously debating whether valuable water resources should be expended on the forestry sector, and if so, whether to charge the forestry sector for water used.

The benefits from employment and other economic linkages, and improved environmental quality (obtained through reduced soil erosion), emanating from the forestry sector must be weighed against the cost of water shortages. It is therefore imperative that any future research on water allocations in an economy-wide context must consider the forestry sector.

Related to the issue of water for the forestry sector is water for the "environmental" sector. Many - especially affluent - South African believe that instream water use is vital to environmental conservation, especially in the country's numerous national parks and wildlife refuges, and should be promoted further in the future (McKenzie, 1993). Detractors, however, claim that such beliefs will ultimately result in keeping poorer segments of the population from using common property resources on such lands. Whatever the case may be, it cannot be disputed that little is known about the actual economic returns to water use in environmental conservation practices, both in terms of revenue from tourism and social benefits derived from ecological conservation.

Given the fervor with which water for environmental conservation use is endorsed, it is necessary to test the validity of these claims, since ecological water allocations could very possibly come at the expense of other productive and consumptive users. In other words, if indeed the Kruger National Park, for example, was to receive a fixed allocation of water - regardless of total water availability in the Olifantsriver Watershed - what would this mean to the other productive sectors of the economy? Who should subsequently bear the brunt of water curtailment policies: would it be the agricultural, the mining or the electricity generation sector? What would the overall welfare implications of such policies be?

The data required to address these concerns is currently unavailable, and it is highly unlikely, that it will be any easier to obtain the information in the near future. However, given the central importance of environmental and forestry water use in the context of the Olifantriver Catchment, and indeed many other watersheds in South Africa, attempts to address these issues with even approximate data will be important first steps in the right direction.

Groundwater use: A considerable proportion of South African water consumption comes from groundwater sources. The Water Act of 1956 determines that water that lies below private land is private, and can be used exclusively by the private owner of that land. Therefore, as in the case of surface waters, groundwater is used lavishly, without any consideration for other concerns such as aquifer depletion, and the environmental effects of such depletion. Despite the enormous difficulties in obtaining reliable data concerning groundwater use, it is an important issue that must be incorporated into future research on water allocations and water management in South Africa.

Like many countries, South Africa faces serious water resource constraints. The continuation of current water use practices threatens to sharply attenuate the development process, especially of those segments that have historically been discriminated against. A more economically, socially and environmentally sustainable approach therefore requires that an appropriate mechanism for water allocation be introduced. This does not necessarily mean water markets, but could mean improved efficiency in administrative allocations. But this does mean that water is valued at a price that better reflects its relative scarcity. The potential efficiency gains from improved water policies do not appear to exact a tremendous price from the disadvantaged sectors - however, small and targeted investments that would improve these sectors' productivity are likely to have great impact.

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Annex 1:
South Africa's water and related legislation

Fundamentally, the current distribution of water resources in South Africa is based on ownership of land and water, and the laws that govern such ownership.

The first post-Union (1910) statutory definition of 'public river' was contained in the Irrigation and Conservation of Waters Act 8 of 1912. The Act defined a public stream as a natural stream of water, which "when it flows, flows in a known and defined channel if the water thereof is capable of being applied to the common use of the riparian owners for purposes of irrigation" (Fuggle and Rabie, p. 655).

No significant legislation relating directly to water was penned or questioned, until 1952, when a Commission of Enquiry was established under the chairmanship of C.G. Hall, to investigate modern water requirements within the framework of existing water legislation. The Commission's findings recommended the explicit recognition of water users other than agriculture. Despite the Commission's proposals for change to the existing water law, the legislation "yet once again remained substantially irrigation-orientated" (Backeberg, 1993, p.6).

Many other recommendations of the Commission were accepted, and eventually included, in the Water Act No. 54 of 1956. While the GNU is considering fundamental re-writing of the country's water law (see the Water Law Review Panel's recommendations to the Minister of Water Affairs and Forestry, 1996), the Act continues to be the most important legislation dealing with the control and use of freshwater resources in South Africa. The definitions of "private" and "public" water as they had been formulated in the Irrigation Act of 1912 formed the basis of the Water Act of 1956.

The Water Act of 1956

The Water Act is based on four different legal systems - all of which find their roots in Europe. The Act pulled together existing water legislation founded on Roman and Roman-Dutch laws, and adaptations to Roman and Roman-Dutch laws that were borrowed from legal precepts from British and later, Anglo-American water laws.

According to the Water Act, water is classified as either public or private. Private water is defined as water which naturally rises, falls, drains or is led onto land but which is not capable of common use for irrigation purposes. Although several provisions of the Act regulate the use of private water, in principle, the owner on whose land it is enjoys sole and exclusive use and enjoyment of it.

Public water is water flowing or found in or derived from the bed of a public stream. A public stream is a natural stream of water which flows in a known and defined channel, if such water can be used for irrigation on two or more pieces of riparian land. The control and use of this water is regulated by the Water Act, and cannot be privately owned. However, private owners can and do have rights - based on their riparian landownership - to divert and use a portion of both the *normal flow* and *surplus flow* of a public stream (ECE Ltd., 1993, Annex A)[1]

Normal flow is defined as that part of a public stream which is derived from a steady source of supply, and which can be used for direct beneficial irrigation without storage. Surplus flow water is defined as all public water which cannot be defined as normal flow water. It may therefore pertain to the following: "water derived from an inconsistent source of supply; groundwater; stagnant water; water, which due to its quantity and quality, cannot be used without prior storage; water of which the flow is too weak for beneficial irrigation" (Backeberg, 1993, p.8).

Under provisions of the law, surplus flow water - like normal flow water - is restricted to the "beneficial utilization for specific purposes." However, in practice, only a court order can refrain the owner of surplus flow water from using more than a "reasonable share". The definition of "reasonable share", however, does not prevent its exclusive utilization by private parties irrespective of downstream needs.

Groundwater is considered private water unless it is drawn from a public stream. Curiously, however, when indeed groundwater is drawn from a public stream, it nonetheless qualifies as surplus flow water, and not as normal flow water. This means that all "public" groundwater - defined as the surplus flow portion of public water - can legally be used exclusively by private parties.

According to the Water Act, wide-ranging discretionary powers both within and beyond *Government Control Areas* are vested in the Ministry of Water Affairs. Private water may not be sold, given, or disposed of by an owner, except with permission of the Minister of Water Affairs. Conveyance or disposal of private water through sale or lease arrangements, without ministerial approval, is considered a public offence. During periods of water shortage, the Ministry of Water Affairs can re-allocate, reduce, restrict or even prohibit existing permits or quotas for water use.

The distinction between public and private water is not altogether clear, as is evident from numerous inconsistencies in the legislation. By adopting principles from previous legislation - such as the Irrigation and Conservation of Waters Act 8 of 1912 - the proviso to the definition of public stream (namely, that water can be used for irrigation on two or more pieces of riparian land, and that private owners have rights based on their riparian landownership) results in some streams may be capable of being public only along certain parts of its course.

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[1] The 1956 Water Act clearly states that ownership in public water does not vest in riparian landowners. The State grants rights of "reasonable use" of the water. Riparian owners can, however, be owners of the banks and beds of such rivers, depending on the provisions of their title deeds. Generally, attached to the title deed is a diagram which indicates whether *ager limitatus* or *ager non limitatus* applies. The latter indicates that ownership of a given piece of riparian land extends to the middle of the stream; the former shows that ownership only extends to the bank of the river (Fuggle and Rabie, 1993, p.296).

The terms 'public' and 'private' water are not defined in such as way as one being the opposite of the other. This allows legal loopholes, so that certain streams can be neither public nor private. It is not altogether clear why there even is a distinction between public and private water, when both classes of water are "used interchangeably in the Act, both referring to running water regulated by the Act" (Fuggle and Rabie, 1992. p.296). The legislation empowers Water Courts to determine whether a body of water is either pubic or private. This clearly points to the lack of accuracy in the Act regarding the distinction between public and private water.

The phrase "capable of common use of irrigation on two or more pieces of land" is another problematic aspect of the Act's definitions. The vagueness of this particular definition allows it to be used almost indiscriminately, since "even the watering of a vegetable garden can be interpreted as irrigation" (Fuggle and Rabie, 1992, p.296). The other troubling aspect of this proviso (that water is public if it is capable of common irrigation on two or more pieces of land) is that it has supported large-scale land holdings. Water, by definition, is for private use if it stems from *one* piece of land - hence creating a legal incentive to acquire or consolidate a large tract of land.[2]

The definition of groundwater - water that falls directly under the land in question - too, supports the tendency to large-scale land holdings. It is legally defined in such a way that groundwater can always be used for exclusive private use. Since land markets throughout the history of South Africa have been significantly distorted, it can be argued that the value of highly-prized groundwater was never completely capitalized in the market price of the land. [3]

Various other peculiarities in the 1956 Water Act exist. Despite the significant strengthening of the public mandate over water resources under the 1956 Act, it appears that certain quasi-public authorities that were historically involved in water management, were exempted from the provisions of the Water Act. For example, the operations of the Rand Water Board, originally established in 1903, and the Vaal River Development Scheme, were governed by a "private Act", the provisions of which are not derogated by the 1956 Water Act (Fuggle and Rabie, 1993, p.299, Department of Water Affairs, 1991, p.7).

While the term '*public interest*' is often encountered in the Water Act, the term is nowhere defined. According to South African law, "public interest is a jurisdictional fact" (Fuggle and Rabie, 1993, p.301), thereby necessitating a definition of public interest. Under the provisions of

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[2] Another caveat to the same proviso: the existence of a stream on two or more pieces of land which is capable of common irrigation on all of them, does not imply that the water is necessarily public water. The reason for this is found in Section 8 of the Water Act: since these pieces of land may be subdivisions of the one *original* piece of land, the water is considered to be private water, and the owner of the subdivision is not entitled to any water rights.

[3] In state-sponsored irrigation areas, large-scale holdings were directly encouraged "in order that the able irrigator may achieve higher yields per unit of water, and practice efficient crop rotation" (Department of Water Affairs, 1986, p.1.47). The argument is based on the premise that "the efficient irrigation farmer will be able to irrigate with his water quota more the average area of land" (Department of Water Affairs, 1986, p.1.47). The underlying logic of this argument is that irrigation efficiency increases with the size of the landholding. Economies of scale in irrigation, however, continue to be debated to this day.

the Water Act, however, the Minister of Water Affairs - who is authorized to apply his discretion concerning water allocations in the public interest - "has a free and subjective discretion to decide whether his administrative act is in the public interest. A court of law cannot therefore adjudicate the objective existence of the jurisdictional fact." (Fuggle and Rabie, 1993, p.301)[4] Not having recourse to an appeals court was not legitimate under the South African Constitution.

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[4] The Court can be appealed to if it is believed that the Minister acted *mala fide* or with an ulterior motive.

Appendix 2:
Sensitivity analysis

The series of experiments that are described in this appendix are not directly related to the "*What if?*" questions asked in the main text. Rather, these model simulations attempt to identify which exogenously set parameters are most important in determining the experiment solutions.

Formal econometric estimation of many model parameters is often not possible, given that the required data is usually poor or insufficient. It is therefore often necessary to make educated 'guess-timates' about the values of important parameters. Since there are a number of exogenous parameters that are used in the Water CGE model - as seen in Table 10 - it is only possible to examine the sensitivity of the results to key parameters.

The sensitivity experiments give the model a partial equilibrium flavor, by allowing a *ceteris paribus* type of analysis: leaving all but one variable unchanged, it becomes easier to understand the workings of the general equilibrium model. Without sensitivity analyses, it would be exceedingly difficult to unravel the complex and intertwined changes in a CGE model, in which all endogenous variables are determined simultaneously.

Implicit Model Assumptions

There are implicit assumptions and structural rigidities associated with each specific functional specification of a CGE model. In this section, some of these inherent assumptions of the Water CGE model are made explicit.

First, it must be re-emphasized that the Water CGE model is a regional model. It is primarily concerned with factor movements - in particular, with respect to land and water factors. However, since it is a regional model where trade - across regional boundaries - is significant, commodity movements attain an equally important rank in the analysis of the model's simulation results. In other words, factor and commodity movements are inextricably linked in general equilibrium models, but in a regional model such as the Water CGE model, trade takes on - by specification - an increased importance in the economy, and must therefore be studied.

As Table A.1 shows, exports and imports constitute a very large share of output (X) and composite domestic demand (Q). Interregional exports and imports - that is, trade outside the region but within the borders of South Africa - figure prominently in the Water CGE model; they constitute on average more than 50 percent of both output and composite domestic demand. International exports and imports (*i.e.* regional trade outside the borders of South Africa) are by comparison much lower, and are indicative of South Africa's past inward-looking and closed trade orientation.

The same pattern also applies to intermediate goods in the regional economy: as Table A.1 indicates (Column 9 entitled 'IMD'), the share of imported intermediates in total intermediate demand is very high. It varies from 53 percent in the electricity and water sectors, all the way to

87 percent in the agricultural subsectors.

The region's trade (both international and interregional) orientation is an important determinant in the simulation results, especially where domestic sectoral prices (PD) are concerned. In general, prices are expected to rise relatively less in those sectors that are more "tradable", because they are more closely linked to external (again, in a regional model this means both international and interregional) markets.[1]

In the regional Water CGE model, the exchange rate - by definition - is held fixed and set to 1. It is then the capital account that adjusts in order to bring the model into equilibrium. This specification stands in contrast to the common specification in most country CGE models, where the balance of trade is fixed, and the country's exchange rate is allowed to vary. In the regional model, in the absence of changes in the exchange rate, trade is affected by 'pure' price differentials between goods for the domestic and external markets, and is not made more or less desirable through currency depreciations or appreciations.

As Figure 1 (in the main text) shows, the specification of technology in the Water CGE model is such that the water and land subfactors are used in fixed coefficients, and there is no direct substitution between the land-water aggregate and intermediate inputs (such as fertilizers and pesticides, which in this model would come from the manufacturing sector). There are, however, substitution possibilities between the land-water aggregate, labor and capital. Thus, in response to changing water (or land) availability and relative factor prices, factor productivity (*i.e.* unit of output per unit of inputs) can be changed, but only by changing sectoral labor and capital employment. The model's structure forces substitution possibilities in sectoral production to be relatively constrained.[2] The model results can therefore be interpreted as an overestimation of the impact of changes in water availability.

All factors and subfactors in the Water CGE are assumed to be perfectly mobile across sectors. The labor factors in the Water CGE are modeled as mobile within the region, and immobile between the region and the outside. Capital, too, is assumed to be regionally mobile. The model solves endogenously for the intersectoral allocation that equates the wage of the factor across sectors, and fully employs the (fixed) aggregate stock of capital and labor types.

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[1] Dervis, de Melo and Robinson define a continuum of sectors that are characterized by different degrees of "tradability". For most purposes, they find it useful to distinguish four groups of sectors: nontradables, exportables, import substitutes and import complements. "A sector can be characterized as producing nontradables if the share of exports in production, and the share of imports in domestic use are very small...A sector producing exportables is characterized by a high ratio of exports in domestic production....Commodities characterized by high shares of imports in total domestic use can be divided into import substitutes and import complements, depending on the ease of substitution between domestic and foreign goods as well as on the sectoral own demand elasticities for the composite good." (Dervis, de Melo and Robinson, 1982, page 240.)

[2] At the same time, however, according to Robinson and Gelhar, substitution between the land-water complex, labor and capital may possibly overstate the actual flexibility of certain sectors, even with low substitution elasticities and fixed coefficients (Robinson and Gelhar, 1994, page 9).

Water and land are also assumed to be mobile within the region. Like capital and labor, the subfactor prices of water and land are uniform across all sectors. Aggregate supplies of land and water are fixed: full employment of the subfactors in this model specification, however, is not required (Equation 9.3). If there is an excess supply of either of the subfactors, their price will be zero (they are free); only when the subfactors are scarce will they have a positive price.

Since the model specification also allows water to move freely from one sector to the other, this implies that land and water can be converted: in the agricultural sectors, from one crop to another (e.g. from horticultural to field crop production), and in the non-agricultural sectors, from one activity to another (and this includes agricultural activity). It should be pointed out that in the model, there are no losses associated with the movement of water from one sector to another.

Especially where labor is concerned (since there is a great level of specificity in this model) there are no wage differentials for the different labor types across sectors; labor in each category moves across economic sectors until the value of its marginal product is the same across sectors. This particular specification eases the welfare interpretation of some of the experiments, because the results are to be understood as the equilibrium or "best" solution. They do not represent a second-best solution (a sort of "disequilibrium" solution), that is brought about by distortions in the factor markets when wage differentials are present. Such a specification may be less realistic for pure policy analysis, but it is convenient when exploring the efficiency aspects of resource movements captured by the model. The reference solution for a model without wage differentials has well-understood efficiency characteristics that would not hold in the presence of a more elaborate specification of factor markets.

Equation 8.1 describes how total household consumption expenditure is allocated among commodities. It shows how sectoral consumption (CD_i) is partly determined by fixed consumption shares $cles_{i,HH}$. This particular formulation simplifies the interpretation of the results, because it implies that the uncompensated (Marshallian) own price elasticity of demand is unity. Hence, the elasticity of response of private final demand due to a change in the sectoral price is the same across the economy. Furthermore, since all consumers are given the same representative demand system through this specification, the effects of any given policy on factoral income distribution are not allowed to feed back through the demand system.

Since the Water CGE assumes full employment for all factors, changes in variables, such as factor and household incomes, and aggregate variables, such as GDP for instance, are small. On the household side, the manner in which the Water CGE model is specified, provides the consumer with an additional buffer to changes in macro variables. To point out one example: changes in government revenue (Equation 7.14) are not transmitted through to the household level of the model. Thus, household incomes have an additional stability factor which does not allow their changes to vary dramatically. Again, this may not be a very accurate representation of reality, but it eases the interpretation of models results.

Sensitivity with Respect to the Factor Substitution Elasticities, σ_i^{P}

The first series of sensitivity experiments examines the importance of the parameter σ_i^p (ρ_i^p in the CES production function (Equation 5.1) equals $1/\sigma_i^p - 1$) when aggregate water supply is cut. Two sets of experiments were run: in each set, the experiments remove water in 5 percent increments, with the last experiment forcing the sectors to use 25 percent less than the base model water allocation. The two sets of experiments differ in the factor substitution elasticities assumed in the ten economic sectors (Table A.2).

As mentioned earlier, given the poor availability of econometric estimates for important parameters - such as σ_i^p, for instance - this set of experiments attempts to establish bounds, by exploring the range of variation in the response of endogenous variables that are conditional upon the parameters.

In the 'high elasticities' set, factor substitution elasticities are assumed to be roughly three to four times larger than those in the "low elasticities" set. In the case of the construction and service sectors, however, the differential between high and low factor substitution elasticities is set lower; with a 3:1 differential which gives low elasticity estimates of approximately 0.08, the base model becomes infeasible.

The factor substitution elasticities vary across sectors: the lower these factor substitution elasticities in a given set, the more difficult it is to substitute between factors, indicating that the sector is assumed to be "locked" into a given production technology. Therefore, within the model's agricultural sector, it is assumed that field crop agriculture, for example, is slightly less flexible in adjusting to relative factor price changes, than are horticultural and 'homeland' agriculture.

As expected, the sensitivity results show that the decreases in the macro-economic indicators are much less pronounced than the decreases in land and water demand. As resources are released - after the economic shock of water curtailment - they find alternate employment. Since the model's specification requires full factor employment, the aggregate changes in the Water CGE model are very small.

Both in high and low factor substitution elasticity experiment set, agricultural output decreases by 0.6 percent after aggregate water is cut by 25 percent; total (agricultural plus non-agricultural) output declines by less than 0.1 percent.

However, where sectoral variables are concerned, the results are often substantially affected by water cuts, both in the high and low factor substitution elasticity experiment sets. As is to be expected, in the experiments with low substitution elasticities, the economy is less able to adjust to the shock of water curtailment by substituting factors: the changes are therefore more pronounced than in the experiments that use the high factor substitution elasticities.

As Table A.3 indicates, domestic output (X) in the agricultural sectors, especially, is severely affected by water cuts. In the low elasticity set, the horticultural sector, which uses water intensively, is very vulnerable to water cuts: its output falls by 37 percent when aggregate water supply is cut by 25 percent. In the high elasticity set, horticultural output falls by 10 percent when water is cut.

The other agricultural sectors are also relatively sensitive to the elasticities of factor substitution - but less than the highly sensitive horticultural sector. Output in livestock agriculture increases by 1.7 percent and 10.6 percent, in the high and low elasticity sets, respectively; output in 'homeland' agriculture increases by 5.6 (high) and 19.4 (low) percent. Field crop agriculture output in the high elasticity set increases by 3.4 percent and by 2.4 in the low elasticity set. The non-agricultural sectors' output is only marginally affected by the changes in factor substitution elasticities, as can be seen from Table A.3. Table A.4 provides more detail by showing the changes in the values of output after each cut in the aggregate water supply, and contrasts the high and low elasticity scenarios.

As Table A.1 indicates, the agricultural subsectors are assumed to be the most "land-water aggregate" intensive crops (Column 4). Table A.5 shows that the agricultural sectors are also the largest absolute users of both water and land resources (subfactors). And as such, the agricultural subsectors experience the largest changes in response to the shock of water curtailment: with water cuts, the sectors substitute away from the increasingly costly water resource towards capital and labor. Within the agricultural sector, the horticultural sector is the most water-intensive (Table A.5, Column 5), and coupled with its relatively low factor substitution elasticity, least able to withstand with changes in the aggregate water supply. Field crop agriculture is the largest user of water and land, but benefits by being relatively less water-intensive. After the first water cuts are instituted, it even experiences a slight increase in its output, as it substitutes away from the land-water aggregate.

Even though all the non-agricultural sectors are relatively more "water-intensive", they are assumed to be less land-water intensive (Column 5 of Table A.5) than the agricultural sectors. (The water intensities for the non-agricultural sectors are measured vis-a-vis their unit land use. This may not be an accurate measure for the non-agricultural sectors, since it would be more appropriate for these sectors to measure their water intensity per unit of output value.) Despite relatively lower factor substitution elasticities (in both the high and low elasticity sets), their output is virtually unaffected by water cuts.

Alternatively expressed, the sectors which have both high land-water aggregate intensities (Column 4 in Table A.1) and high water-land ratios (Column 5 in Table A.5) will suffer most dramatically from the cuts in aggregate water supply. Therefore, within the agricultural sector, horticulture is expected to suffer most. Even though the non-agricultural sectors have very high water-land ratios (Table A.5), they are relatively less land (i.e. land-water aggregate) intensive, and are therefore expected to suffer less in the face of aggregate water cuts. Table A.4 shows the changes in sectoral water use (millions of cubic meters) and land use (millions of hectares) - both for the high and low substitution scenarios - as aggregate water is cut incrementally.

The same pattern - i.e. relatively large changes in the agricultural sectors and negligible changes in the non-agricultural sectors - also applies to other endogenous variables such private consumption, domestic sales (D) and exports (E), as Table A.3 indicates. Again, the agricultural sectors are relatively more sensitive to the factor substitution elasticities than are the non-agricultural sectors which are relatively less sensitive.

The stimuli to these changes are domestic prices (PD). Domestic prices increase as demand increases, and demand increases for those sectors that use water less intensively. According to the Stolper-Samuelson theorem, an increase in the relative price of one commodity raises the real return of the factor that is used intensively in the production of that commodity, and lowers the real return to the other factor. Therefore, as water cuts raise the price of water, the demand for less water-intensive goods increases. This in turn will raise the returns to the factors used intensively in the production of the less water-intensive sectors (i.e. capital and labor). However, since the aggregate supply of water is cut in these experiments, the price increases of water are larger than the rental and wage increases of capital and labor. Hence, as Table A.3 shows, domestic prices increase more in water-intensive sectors than in those sectors that use water less intensively (horticulture versus 'homeland' agriculture, for example).

At the same time, the change in PD is lower, the larger the ratio E/D. As Table A.1 (Column 12) shows, the mining sector is has the highest E/D ratio (20 times more sales to the domestic market than to export markets). The other sectors, too, all have E/D ratios larger than 1. This helps to explain why changes in PD are especially small in the non-agricultural sectors (both high and low elasticity sets), where the land-water intensity ratios are much smaller to begin with. By the same token, the relatively larger changes in PD in the agricultural sectors are explained by the larger land-water intensity ratios, which outweigh the larger E/D ratios (the countervailing tendency, that would reduce changes in PD). Again, it must be re-iterated that the E/D values are high, because the Water CGE model is regional.

As Table A.3 shows, sectoral land and water demands, however, are highly sensitive to the changes in factor substitution elasticities in the face of water cuts. Since water-land coefficients are fixed in the Water CGE (on the subfactoral level), sectoral water and land demands experience equal changes (Table A.3). It should be pointed out that the percentage changes in water and land demands, according to high and low substitution elasticities, may be slightly different due to rounding errors and to slightly different base solutions.

Again, field crop agriculture's demand for water and land is much less volatile than that of the other agricultural subsectors: between the high and low elasticity sets, the sector's water and land demand changes by a mere 1.8 percentage points. The other sectors experience much larger percentage changes between the high and low factor substitution sets (horticulture-16, livestock-9 and 'homeland' agriculture-15 percentage points). The non-agricultural sectors vary their water and land demand nearly as dramatically as the agricultural sectors, as Table A.3 shows. The sectors with low land-water aggregate intensities and low water (vs. land) intensities - like manufacturing and construction - adjust their demands the least.

Sensitivity with Respect to the Armington Substitution Elasticities, σ_i^c

The second series of sensitivity experiments examines the importance of the parameter σ_i^c (ρ_i^c in the CES function (Equation 5.4) equals $1/\sigma_i^c - 1$) when aggregate water supply is cut. Two sets of experiments were run: in each of these sets, the experiments remove water in 5 percent increments, with the last experiment forcing the sectors to use 25 percent less than the base model water allocation. The two sets of experiments differ in their sectoral Armington substitution elasticities (Table A.2).

The lower the Armington substitution elasticities are set, the higher is the assumed level of product differentiation (due to quality differences, for example). Therefore, agricultural products such as grains (produced in the field crop agricultural sector) are assumed to be fairly homogeneous in quality, and are therefore assumed to have a relatively higher factor substitution elasticity.

When the values for σ_i^c are greater than one, then in response to factor price changes, substitution effects are larger than income effects; when they are smaller than one, income effects are larger than substitution effects. Substitution effects are equal to income effects when σ_i^c is equal to 1. Hence, when σ_i^p is greater than one, the response of the economy to a shock is to contract exports and imports, and produce more of the domestic substitute. In developing countries, σ_i^c's are usually assumed to have values that are smaller than one; in developed countries, these substitution elasticities are usually assumed to be larger. In the case of South Africa, these elasticities are assumed to have relatively smaller values, given the country's past inward-looking trade orientation which did not permit a high degree of substitution.

Nonetheless, given the regional character of the model, where external trade to both international and interregional markets is large, the values for Armington substitution elasticities are set to be on the higher end of a low spectrum that is usually assumed for Armington substitution elasticities. Since trade shares - both on the export and import side - are large, it is expected that the model results are sensitive to changes in the Armington substitution elasticities. An analysis of the sensitivity of the model results to the Armington substitution elasticities confirms this expectation.

As described earlier, the impetus to changes in the model stems from changes in PD. These changes are lower, the larger the ratio of exports to domestic sales and the smaller the ratio of imports to domestic use. When E/D is large, then there exists an export outlet for the region's output; the possibility of D swamping the domestic market is reduced and changes in PD are minimized. This together with a high elasticity of demand results in lowering the changes in PD.

Elasticities of demand are approximated with the ratio CD/Q (Column 10 in Table A.1): the higher the ratio, the higher the elasticity of demand. In the Water CGE model, the transport, field crop agriculture and service sectors have the highest CD/Q ratios, with 0.47, 0.36 and 0.34, respectively. These characteristics help minimize the change in PD in these sectors, but especially in field crop agriculture. The other agricultural subsectors (horticulture, livestock and 'homeland' agriculture) have relatively lower demand elasticities, and therefore, experience larger changes in PD (see Table A.6).

It is also possible to understand the percentage change in PD (and D) as an increasing function of the cross-price elasticity of (final) demand for the domestic good. This cross-price elasticity, in turn, is associated with a large spread between the elasticity of demand for the composite good (ϵ^D) and the Armington elasticity of substitution. Large changes in D and PD will result when it is easy to substitute D for the foreign produced good M (i.e. σ_i^c is high); when the sector has a large import share; and when the demand for Q is relatively insensitive to a change in its price (i.e. demand is inelastic). These factors, in conjunction with possibly a low elasticity of domestic supply, will result in dramatic increases in PD (Tables A.6 and A.7).

According to Dervis, de Melo and Robinson, however, "there is no simple rule of thumb that gives the domestic price response as trade elasticities are uniformly and systematically varied." (Dervis, de Melo and Robinson, 1982, page 270) Changes in the general equilibrium framework are complex and intertwined, and all PD's must be analyzed on a sector-by-sector basis.

Again, as in the first set of experiments, it is the agricultural sector which experiences the largest changes - both absolutely and relatively - when the Armington substitution elasticities are varied, while the non-agricultural sectors are less vulnerable to the economic shock of water cuts.

Aggregate indicators like agricultural output and GDP vary minimally in the high and low Armington elasticity sensitivity experiments: agricultural output declines by 0.5 in the high set, by 0.4 in the low set; GDP changes by 0.1 percent in both the high and low sets.

Sectoral variables such as output, domestic sales and exports are less robust to the economic shock of water curtailment (Table A.6). Domestic composite demand (Q) and imports (M) are very stable to shocks and initial Armington values, since in the Water CGE model specification, household incomes are robust in the face of economic shocks.

As seen in Tables A.6 and A.8, water and land uses do not vary substantially between the high and low Armington substitution elasticity sets. As above, the sectors with low land-water intensities and low water intensities adjust their water and land demands the least, when the aggregate water supply is cut.

Sensitivity with Respect to Initial Land and Water (Subfactor) Price Assumptions

The third series of experiments is designed to test the sensitivity of the results to initial values of the model's subfactor (land and water) prices. This information, together with empirical data concerning sectoral water and land use (in millions of cubic meters and millions of hectares, respectively), determines the values of land and water payments that are recorded in the base SAM. These values, in turn, lock the economic system into certain assumptions concerning the production structure vis-a-vis land and water used by the different economic sectors.

To illustrate, with a (rental) price of 50 Rand per hectare of land and 0.03 Rand per cubic meter of water, the agricultural field crop sector pays 153 million Rand for land, and 15 million Rand for water (Columns 5 and 6 in Table A.9). From the IO tables, gross operating surplus (value added paid to non-labor factors) is 470 million Rand (Column 8). Hence, capital payments are assumed to be 470 million Rand minus 153 million Rand minus 15 million Rand, or 302 million Rand (Column 9 equals Column 8 minus Column 5 minus Column 6). These numbers imply that 91 percent of land-water payments go to land, 9 percent to water; 64 percent of gross operating surplus is attributable to capital, the rest to the land-water aggregate (Table A.9).

In summary, therefore, the initial values of land and water prices determine the SAM values; and this series of experiments attempts to determine the sensitivity of the model results to these base values.

On an aggregate level, the changes to agricultural output, real and nominal GDP are nil. Production, exports, imports, and consumption are almost completely unaffected by the changes in the initial values of land and water prices (Table A.10 shows the effects on production and exports, as example).

On the subfactor level, on the other hand, the changes are more noticeable, as Table A.11 shows. As water is made cheaper, the less water-intensive sectors reduce their demand for land and water by more than the more water-intensive sectors (for example, the agricultural sectors vs. construction); and analogously, as land is made cheaper, the less land-intensive sectors reduce their demand for land and water by more than the more land-intensive sectors (agriculture vs. services).

The largest change in the demand for water is a 13 percentage point change (in construction) when the price of water is decreased by 100 percent; when the price of land is reduced by 33 percent, the largest change in water demand is 8 percentage points (in services).

In summary, the base model results are quite insensitive to the assumptions regarding the initial subfactor prices; however, land and water demands are moderately more sensitive. It is expected, that when these changes are coupled with economic shocks - like cuts in the aggregate water supply - that the model results will be vary dramatically between experiments.

Sensitivity with Respect to Initial Water (Subfactor) Use Assumptions

In order to test whether the initial assumptions do matter when coupled with economic shocks, the following tests were conducted (in this particular series of experiments, different assumptions concerning the initial values of water *use*, rather than water *price*, were made): the first base model assumes that 'homeland' agriculture uses 19 million cubic meters; the model is subsequently subjected to five incremental cuts of 15 percent in the aggregate water supply. The second base model assumes that 'homeland' agriculture uses 15 million cubic meters; the second set of experiments decreases the aggregate water supply by 15 percent cuts.

Table A.12 shows the results of this sensitivity experiment: even though base model 1 and 2 are virtually identical (they differ only in the water use of 'homeland' agriculture), after water is cut by 75 percent, the two sets of experiments yield dramatically different results, especially where 'homeland' agriculture is concerned. By changing the initial water use figure for 'homeland' agriculture, its water-land ratio decreases from 136 cubic meters per hectare to 107 cubic meters per hectare. With reduced water-intensity, the 'homeland' agricultural sector is dramatically better suited to withstand the shock of water cuts, as Table A.12 shows.

Since any information concerning the 'homelands' is notoriously unreliable, these sensitivity results point to the crucial importance of using more reliable data.

Table 11: Water use changes
(percentage change relative to base)

	Base (mill. of m3)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	4.99	2.20	3.50	-0.10	-28.90	-61.40
Horticultural agriculture	2.71	-25.00	-51.70	-77.50	-87.10	-91.00
Livestock agriculture	0.50	5.00	14.50	46.10	64.40	21.00
Homeland agriculture	0.19	6.50	16.10	38.20	2.20	-54.30
Mining	3.01	-22.90	-47.60	-72.60	-83.10	-87.80
Manufacturing	2.51	-30.70	-57.20	-79.30	-87.50	-91.10
Transport	0.03	-4.00	-8.00	-16.00	-32.00	-44.00
Electricity and water	1.90	-20.60	-40.70	-61.40	-71.20	-76.20
Construction	0.06	-1.80	-7.30	-18.20	-27.30	-32.70
Services	0.02	4.80	4.80	14.30	19.00	9.50

Table 12: Output changes
(percentage change relative to base)

	Base (bill. R)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	1.01	1.80	3.00	0.30	-22.20	-50.30
Horticultural agriculture	0.69	-7.00	-16.60	-30.50	-37.20	-39.30
Livestock agriculture	1.88	1.40	3.80	10.00	18.60	22.60
Homeland agriculture	0.04	5.70	14.30	34.30	2.90	-45.70
Mining	12.34	-0.10	-0.30	-0.60	-0.40	0.50
Manufacturing	57.46	0.00	0.00	0.10	0.00	-0.20
Transport	7.75	0.10	0.30	0.60	0.90	1.20
Electricity and water	7.85	-0.20	-0.60	-1.70	-2.60	-3.00
Construction	9.78	0.00	0.10	0.10	0.20	0.30
Services	44.78	0.00	0.10	0.10	0.10	0.20

Table 13: Domestic composite demand changes
(percentage change relative to base)

	Base (bill. R)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	2.48	0.00	0.10	0.10	-0.40	-1.40
Horticultural agriculture	1.33	-0.10	-0.20	-0.20	-0.50	-0.90
Livestock agriculture	3.64	0.00	0.10	0.20	0.00	-0.40
Homeland agriculture	0.07	0.00	0.00	0.00	0.00	-1.50
Mining	5.80	0.00	-0.10	-0.20	-0.40	-0.70
Manufacturing	53.48	0.00	0.00	0.10	0.00	-0.20
Transport	7.86	0.00	0.10	0.10	0.10	-0.10
Electricity and water	5.73	0.00	-0.10	-0.30	-0.60	-0.80
Construction	9.27	0.00	0.00	0.00	0.10	0.00
Services	35.87	0.00	0.10	0.10	0.10	0.00

Table 14: Domestic sales changes
(percentage change relative to base)

	Base (bill. R)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	0.21	1.00	1.90	0.00	-16.40	-39.60
Horticultural agriculture	0.14	-3.60	-9.30	-17.90	-22.10	-24.30
Livestock agriculture	0.39	0.50	1.80	5.20	9.40	10.90
Homeland agriculture	0.01	0.00	0.00	14.30	0.00	-42.90
Mining	0.59	-0.20	-0.20	-0.30	-0.50	-0.30
Manufacturing	21.28	0.00	0.00	0.10	0.00	-0.20
Transport	0.23	0.10	0.20	0.30	0.40	0.50
Electricity and water	1.56	-0.10	-0.40	-1.00	-1.60	-1.90
Construction	4.45	0.00	0.00	0.10	0.10	0.10
Services	19.87	0.00	0.10	0.10	0.10	0.00

Table 15: Private consumption changes
(percentage change relative to base)

	Base (bill. R)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	0.89	0.10	0.20	0.20	-0.90	-2.70
Horticultural agriculture	0.25	-0.40	-0.80	-1.20	-2.00	-2.40
Livestock agriculture	0.69	0.10	0.30	0.60	0.70	0.70
Homeland agriculture	0.01	0.00	9.10	9.10	9.10	0.00
Mining	0.04	2.70	2.70	2.70	2.70	0.00
Manufacturing	13.50	0.00	0.10	0.20	0.10	-0.20
Transport	3.67	0.10	0.10	0.20	0.20	0.00
Electricity and water	1.53	0.10	0.10	0.10	-0.10	-0.50
Construction	0.04	2.30	4.70	7.00	4.70	-2.30
Services	12.06	0.10	0.10	0.20	0.20	0.00

Table 16: Export changes
(percentage change relative to base)

	Base (bill. R)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	0.80	2.00	3.20	0.40	-23.80	-53.60
Horticultural agriculture	0.55	-7.90	-18.70	-34.10	-41.50	-43.70
Livestock agriculture	1.49	1.50	4.30	11.20	21.00	25.40
Homeland agriculture	0.03	3.40	13.80	34.50	3.40	-51.70
Mining	11.76	-0.10	-0.30	-0.60	-0.30	0.60
Manufacturing	36.18	0.00	0.00	0.10	0.00	-0.20
Transport	5.51	0.10	0.30	0.70	1.10	1.50
Electricity and water	6.29	-0.20	-0.70	-1.80	-2.80	-3.20
Construction	5.33	0.00	0.10	0.20	0.30	0.50
Services	24.91	0.00	0.10	0.10	0.20	0.30

Table 17: Import changes
(percentage change relative to base)

	Base (bill. R)	-15%	-30%	-45%	-60%	-75%
Field crop agriculture	2.27	0.00	-0.10	0.10	1.10	2.70
Horticultural agriculture	1.19	0.30	1.00	2.00	2.40	2.00
Livestock agriculture	3.26	-0.10	-0.20	-0.50	-1.00	-1.70
Homeland agriculture	0.01	0.00	0.00	-1.60	0.00	3.30
Mining	5.21	0.00	-0.10	-0.20	-0.40	-0.80
Manufacturing	32.19	0.00	0.00	0.10	0.00	-0.20
Transport	5.63	0.00	0.00	0.10	-0.10	-0.30
Electricity and water	4.17	0.00	0.00	-0.10	-0.20	-0.40
Construction	4.82	0.00	0.00	0.00	0.00	0.00
Services	16.01	0.00	0.00	0.10	0.00	-0.10

Table 18: Land and water use in the Olifantsriver Watershed

	(1) Land use (mill. ha)	(2) Percent of total	(3) Water use (mill. m3)	(4) Percent of total	(5) Water/ land ratio (m3/ha)
Field crop agriculture	3.06	72.2	500	31.1	163
Horticultural agriculture	0.19	4.5	270	16.8	1,421
Livestock agriculture	0.57	13.4	50	3.1	88
Homeland agriculture	0.14	3.3	19	1.2	136
Mining	0.16	3.8	300	18.6	1,875
Manufacturing	0.05	1.2	250	15.5	5,000
Transport	0.01	0.2	3	0.2	300
Electricity and water	0.02	0.5	192	11.9	9,600
Construction	0.01	0.2	6	0.4	600
Services	0.03	0.7	20	1.2	667
TOTAL	4.24	100.0	1,610	100.0	
	(1b)	(2b)	(3b)	(4b)	(5b)
Lands and Water Use in the Olifantsriver Watershed (used in sensitivity analysis towards initial water use assumptions)					
Field crop agriculture	3.06	72.2	500	31.1	163
Horticultural agriculture	0.19	4.5	270	16.8	1,421
Livestock agriculture	0.57	13.4	50	3.1	88
Homeland agriculture	0.14	3.3	15	0.9	107
Mining	0.16	3.8	300	18.7	1,875
Manufacturing	0.05	1.2	250	15.6	5,000
Transport	0.01	0.2	3	0.2	300
Electricity and water	0.02	0.5	192	12.0	9,600
Construction	0.01	0.2	6	0.4	600
Services	0.03	0.7	20	1.2	667
TOTAL	4.24	100.0	1,606	100.0	

Table 19: Implicit factor and subfactor use assumptions used in the Social Accounting Matrix

	(1) Land use (mill. ha)	(2) Water use (mill. m3)	(3) Price of land (R/ha)	(4) Price of water (R/ha)	(5) = (1) * (3) Value of land (bill. R)	(6) = (2) * (4) Value of water (bill. R)	(7) = (5) + (6) Value of land-water aggregate (bill. R)
Field crop agriculture	3.06	500.00	50.00	0.03	0.153	0.015	0.168
Horticultural agriculture	0.19	270.00	50.00	0.03	0.010	0.008	0.018
Livestock agriculture	0.57	50.00	50.00	0.03	0.029	0.002	0.030
Homeland agriculture	0.14	18.75	50.00	0.03	0.007	0.001	0.007
Mining	0.16	300.00	50.00	0.03	0.008	0.009	0.017
Manufacturing	0.05	250.00	50.00	0.03	0.003	0.008	0.010
Transport	0.01	3.00	50.00	0.03	0.000	0.000	0.000
Electricity	0.02	192.00	50.00	0.03	0.001	0.006	0.007
Construction	0.01	6.00	50.00	0.03	0.000	0.000	0.000
Services	0.03	20.00	50.00	0.03	0.001	0.002	0.002
	(8) GOS* from IO tables (bill. R)	(9) = (8) - (7) Resultant capital (bill. R)	(10) = (5)/(7) Percent of land in land-water aggregate	(11) = (6)/(7) Percent of water in land-water aggregate	(12) = (9)/(8) Percent of capital in GOS	(13) = (7)/(8) Percent of land water aggregate in GOS	
Field crop agriculture	0.47	0.30	0.91	0.09	0.64	0.36	
Horticultural agriculture	0.32	0.30	0.54	0.46	0.94	0.06	
Livestock agriculture	0.87	0.84	0.95	0.05	0.97	0.03	
Homeland agriculture	0.02	0.01	0.92	0.08	0.56	0.44	
Mining	5.66	5.64	0.48	0.52	1.00	0.00	
Manufacturing	6.55	6.54	0.27	0.73	1.00	0.00	
Transport	2.11	2.11	0.75	0.25	1.00	0.00	
Electricity	3.33	3.32	0.12	0.88	1.00	0.00	
Construction	0.41	0.41	0.60	0.40	1.00	0.00	
Services	7.64	7.64	0.69	0.31	1.00	0.00	

* Gross operating surplus - value-added paid out to non-labor factors (capital and land-water aggregate).

Note: Percent based on monetary values, not physical amounts.

Table 20: Output, domestic demand and export changes as a result of land and water reform simulations

1. Combined effects of 25 percent cut in land and 25 percent productivity boost in homeland agriculture
(percentage change relative to base solution)

	Water demand	Output	Domestic demand	Exports
Field crop agriculture	-39.90	-31.70	-24.20	-34.00
Horticultural agriculture	7.50	7.40	4.30	8.30
Livestock agriculture	-24.40	0.10	-0.30	0.10
Homeland agriculture	181.70	297.10	128.60	317.20
Mining	7.90	0.60	0.20	0.60
Manufacturing	33.20	-0.20	-0.20	-0.20
Transport	-12.00	0.10	-0.10	0.10
Electricity and water	26.60	0.80	-0.30	0.90
Construction	-3.60	0.00	0.00	0.00
Services	-4.80	0.00	-0.10	0.00

2. Combined effects of 25 percent cut in water and 5 percent land-water productivity boost in homeland agriculture
(percentage change relative to base solution)

	Water demand	Output	Domestic demand	Exports
Field crop agriculture	1.90	1.70	1.00	1.90
Horticultural agriculture	-41.00	-12.40	-6.40	-13.90
Livestock agriculture	8.90	2.60	1.30	2.90
Homeland agriculture	33.00	22.50	14.30	24.20
Mining	-37.70	-0.20	-0.20	-0.20
Manufacturing	-47.30	0.00	0.00	0.00
Transport	-4.00	0.20	0.10	0.20
Electricity and water	-32.80	-0.40	0.30	-0.40
Construction	-5.50	0.00	0.00	0.10
Services	4.80	0.00	0.00	0.00

2. Combined effects of 25 percent cut in water and identical technology in field crop and homeland agriculture
(percentage change relative to base solution)

Field crop agriculture	2.50	2.10	1.50	2.30
Horticultural agriculture	-41.30	-12.50	-6.40	-14.10
Livestock agriculture	9.50	2.70	1.30	2.90
Homeland agriculture	25.00	17.50	14.30	18.20
Mining	-38.00	-0.20	-0.20	-0.20
Manufacturing	-47.60	0.00	0.00	0.00
Transport	-4.00	0.20	0.10	0.20
Electricity and water	-33.10	-0.40	-0.30	-0.40
Construction	-5.50	0.00	0.00	0.10
Services	4.80	0.00	0.00	0.00

Table 21: Macro changes as a result of land and water reform simulations
(in billions of Rand)

	Base	25% land cuts + 25% productivity boost to homeland agriculture	25% water cuts + 5% productivity boost to homeland agriculture	25% water cuts + identical technology in field crop and homeland agriculture
Land-water income	0.26	0.21	0.25	0.25
Agricultural output	3.61	3.44	3.60	3.60
Total ouput (nominal)	143.57	143.44	143.54	143.54
Total output (real)	151.87	151.73	151.85	151.84
Foreign savings	-11.30	-11.36	-11.29	-11.28

Figure 1: Sectoral production technology

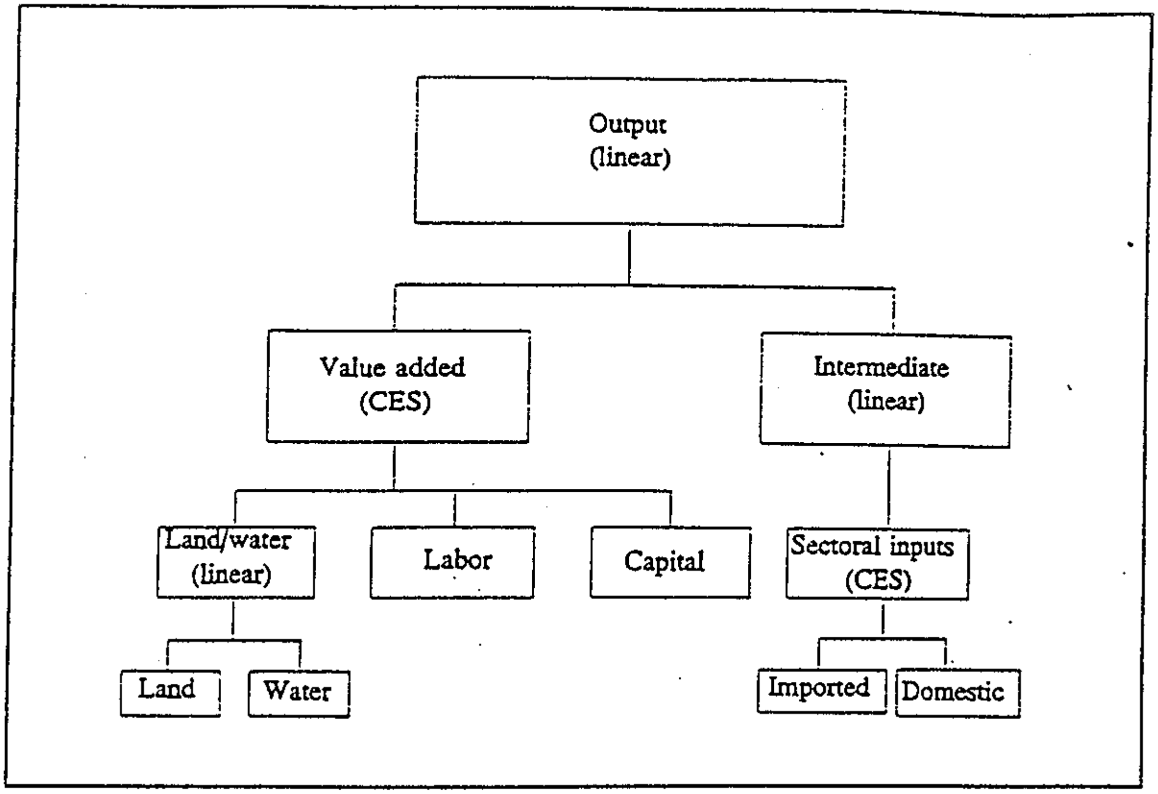


Figure 2: Demand for water

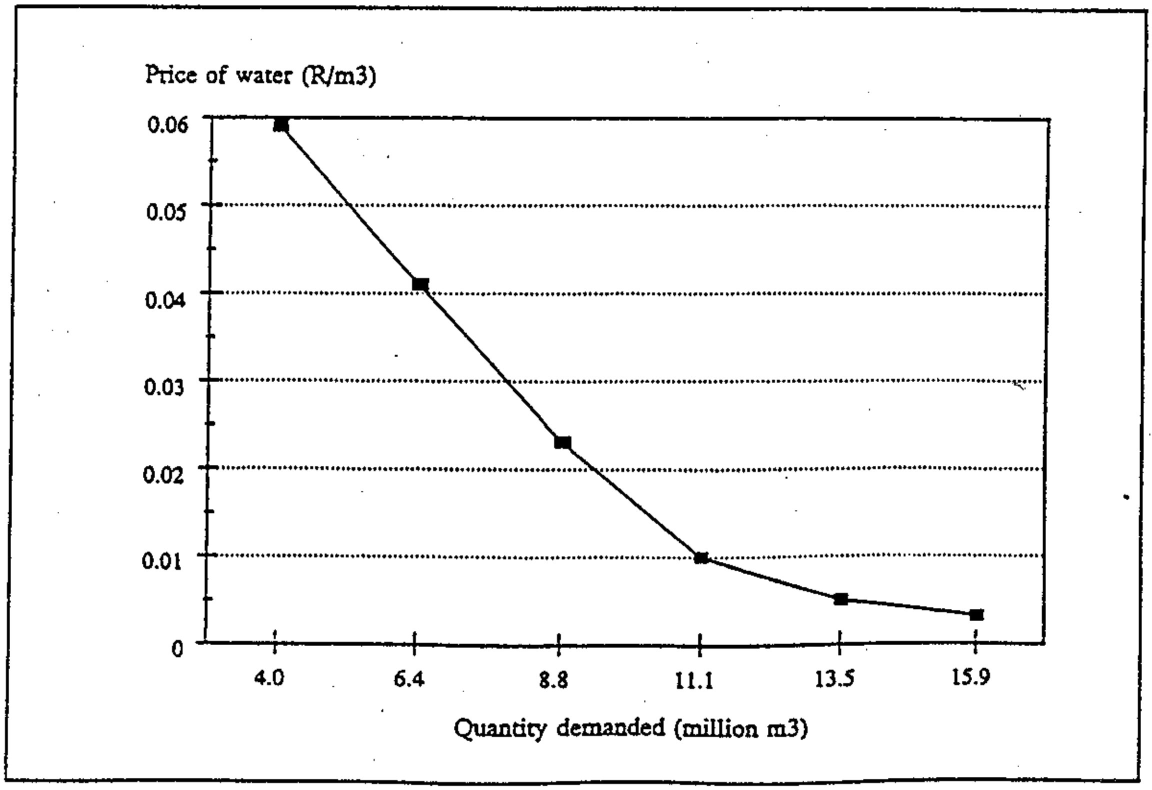


Figure 3: Land-water aggregate use

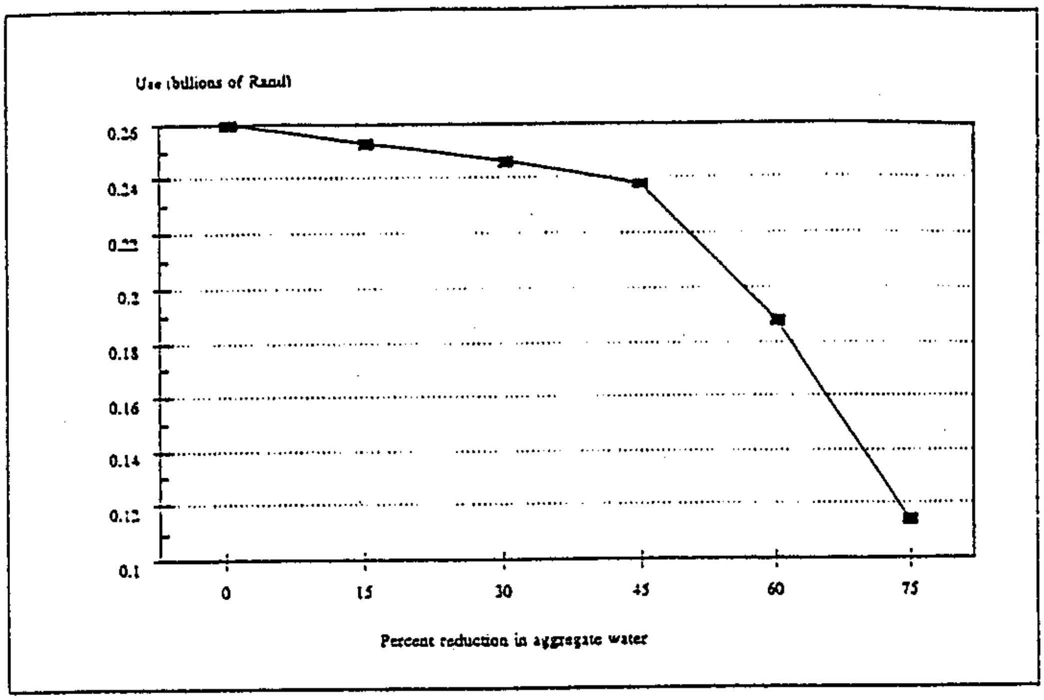


Figure 4: Land and water prices

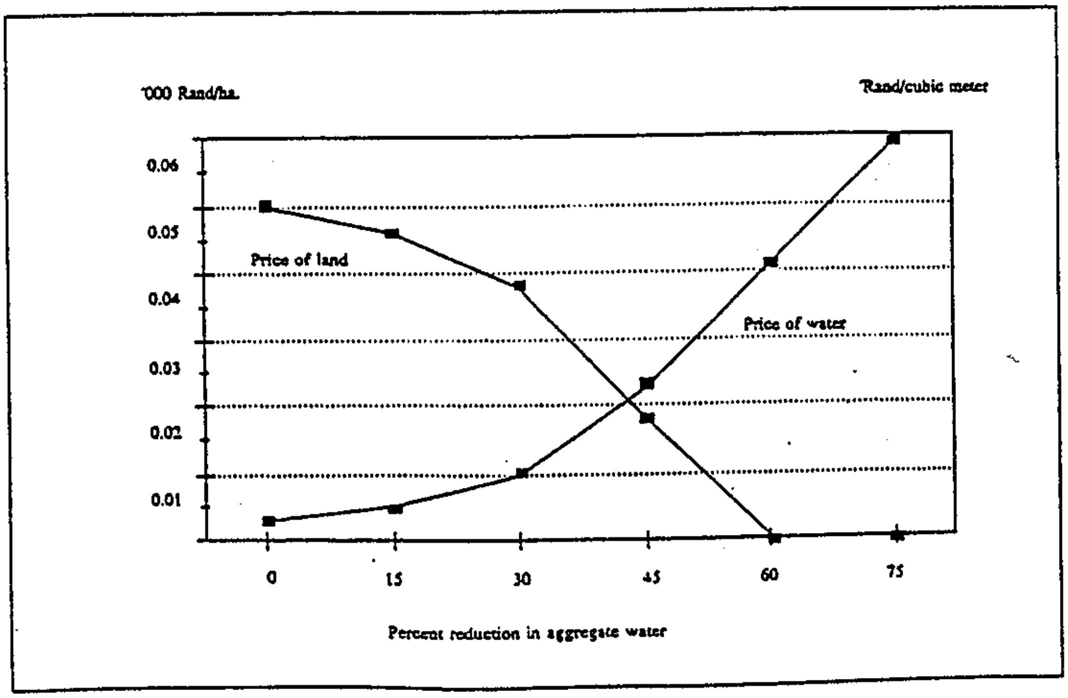


Figure 5: Sectoral water use

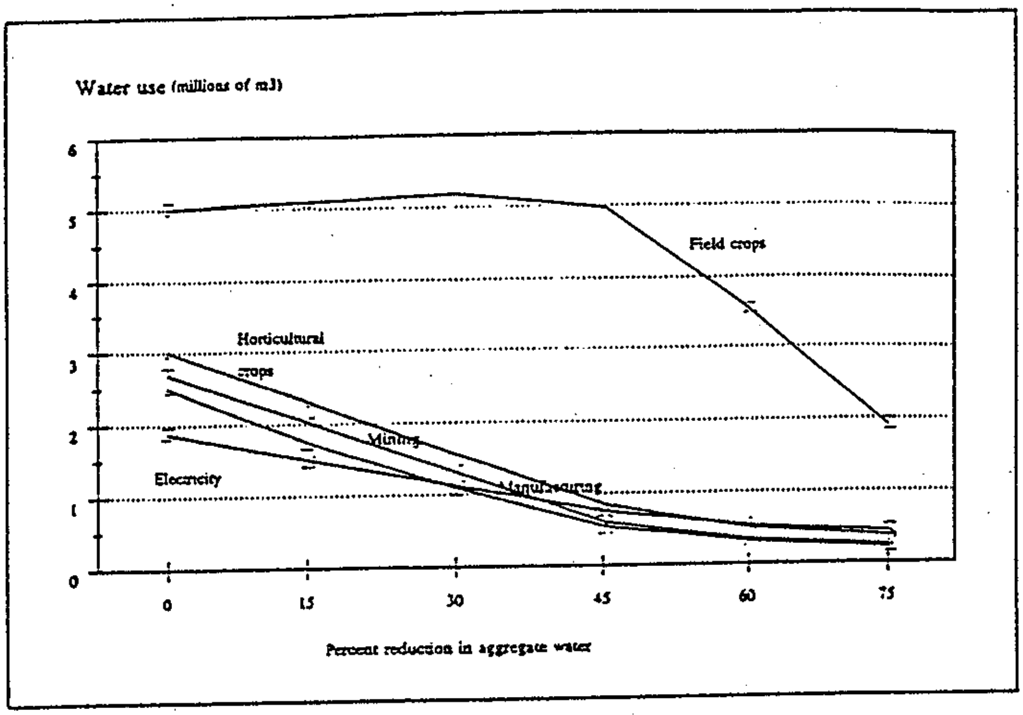


Figure 6: Sectoral water use

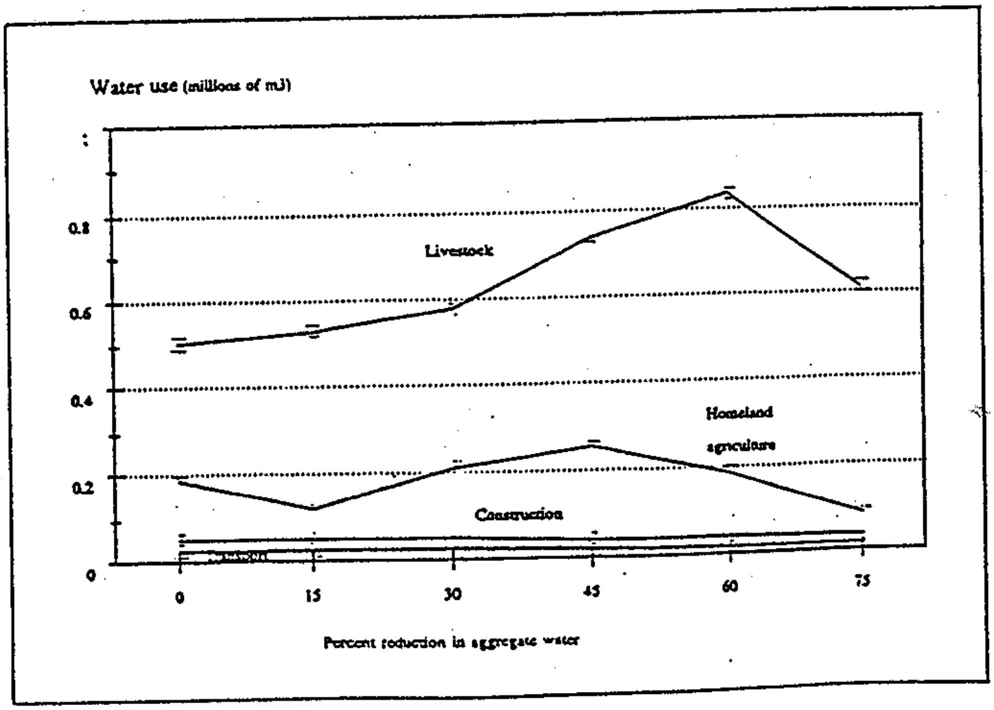


Figure 7: Sectoral land use

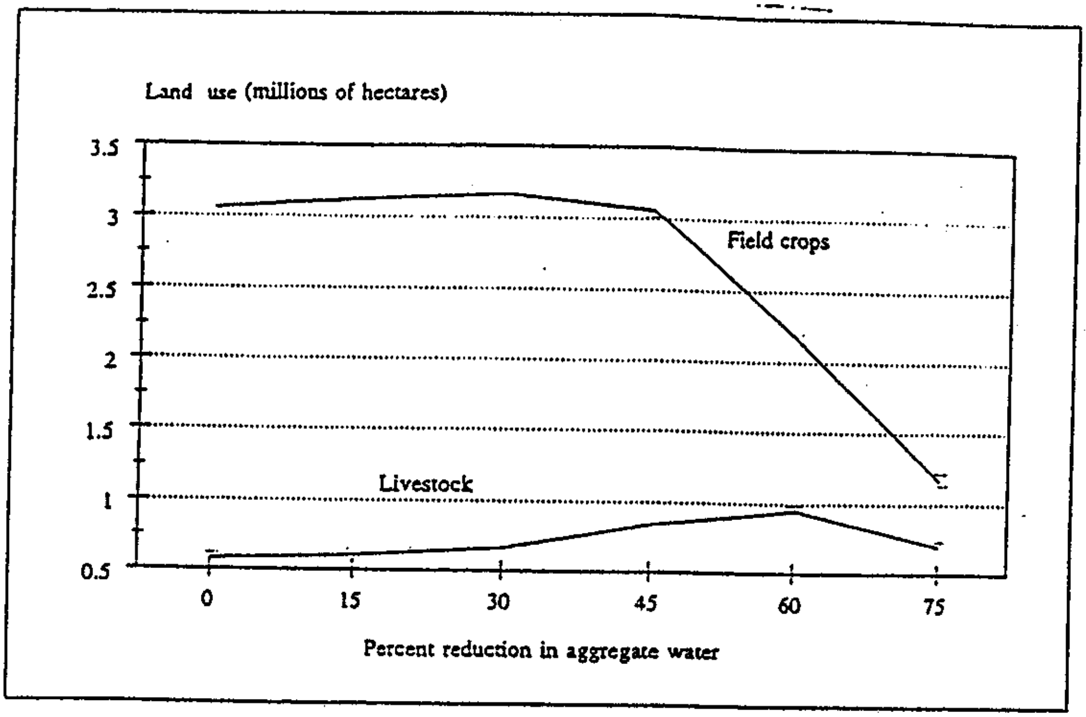


Figure 8: Sectoral land use

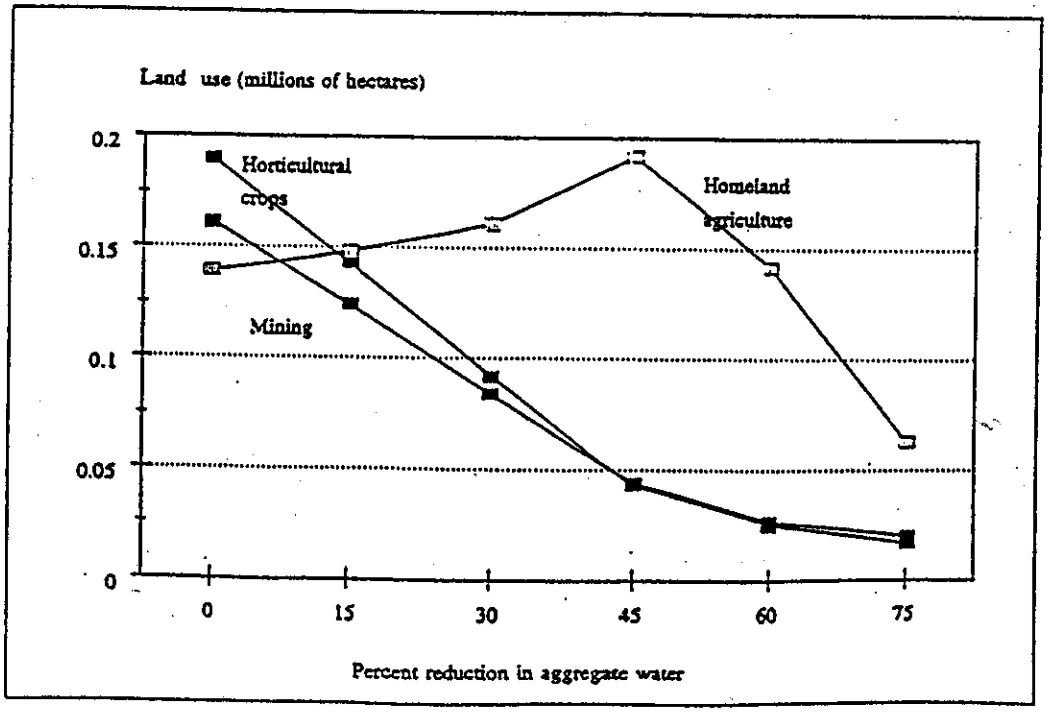
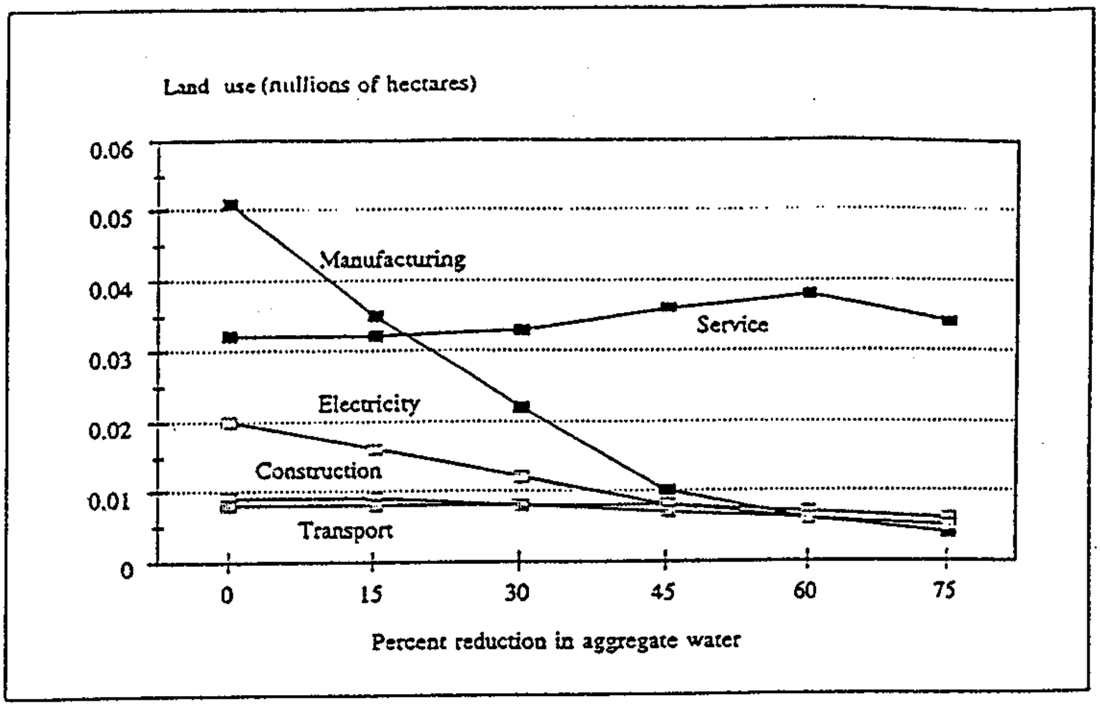


Figure 9: Sectoral land use



Annex Table 1: Structure of the regional economy in the base solution

	Billion Rand		Ratio of values		Percent	
	(1) Output	(2) Demand	(3) Capital/ labor	(4) Land/ labor	(5) ENAT/X	(6) EREG/X
Field crop agriculture	1.007	2.478	2.15	0.92	8.3	71.2
Horticultural agriculture	0.686	1.331	2.15	0.92	8.3	71.2
Livestock agriculture	1.879	3.642	2.15	0.92	8.3	71.2
Homeland agriculture	0.035	0.068	2.18	0.96	8.6	73.1
Mining	12.343	5.798	1.40	0.60	9.52[a]	
Manufacturing	57.463	53.476	0.48	0.20	11.8	51.2
Transport	7.749	7.859	0.45	0.19	36.1	35.0
Electricity and water	7.848	5.726	1.86	0.80	0.6	79.5
Construction	9.775	9.265	0.13	0.05	0.1	54.4
Services	44.779	35.873	0.27	0.11	4.8	50.9
TOTAL	143.564	125.516				

	Percent		Ratio			
	(7) MNAT/Q	(8) MREG/Q	(9) IMD	(10) CD/Q	(11) ID/Q	(12) E/D
Field crop agriculture	3.8	62.1	0.87	0.36	0.02	3.88
Horticultural agriculture	4.8	78.4	0.87	0.19	0.02	3.89
Livestock agriculture	4.8	78.5	0.87	0.19	0.02	3.88
Homeland agriculture	4.9	79.8	0.87	0.16	0.02	4.14
Mining	47.8	40.7	0.81	0.01	0.00	19.99
Manufacturing	17.9	33.6	0.72	0.25	0.04	1.70
Transport	9.0	52.2	0.65	0.47	0.04	2.47
Electricity and water	0.0	64.0	0.53	0.27	0.00	4.03
Construction	0.0	48.1	0.66	0.00	0.74	1.20
Services	1.7	38.0	0.63	0.34	0.20	1.25

Legend: Column 1 = regional output; Column 2 = regional domestic composite demand; Column 3 = value of capital as ratio of value of labor; Column 4 = value of land as ratio of value of labor; Column 5 = international exports as percentage of total output; Column 6 = international exports as percentage of total output; Column 7 = international imports as percentage of domestic consumption; Column 8 = interregional imports as percentage of domestic consumption; Column 9 = Share of imported intermediate inputs in total intermediate inputs; Column 10 = private consumption as a share of total domestic demand; Column 11 = investment as a share of total domestic demand; Column 12 = Exports as a percentage of domestic sales.

[a] International and interregional exports (combined as percentage of total output.

Annex Table 2: Alternative factor and Armington substitution elasticities

	High	Low
Factor substitution elasticities:		
Field crop agriculture	0.80	0.20
Horticultural agriculture	1.10	0.30
Livestock agriculture	0.80	0.20
Homeland agriculture	1.10	0.30
Mining	1.10	0.30
Manufacturing	1.10	0.30
Transport	0.75	0.25
Electricity and water	0.75	0.25
Construction	0.25	0.18
Services	0.25	0.18
Armington substitution elasticities:		
Field crop agriculture	6.00	2.00
Horticultural agriculture	2.00	0.66
Livestock agriculture	2.00	0.66
Homeland agriculture	1.10	0.30
Mining	1.10	0.30
Manufacturing	3.00	0.90
Transport	0.75	0.25
Electricity and water	0.75	0.25
Construction	0.25	0.08
Services	0.25	0.08

Annex Table 3: Resource pull effects of a 25% cut in aggregate water supply under high and low factor substitution elasticities

(percent change relative to base solution)

	Water demand		Land demand		Output (X)		Domestic demand (Q)		Domestic sales (D)		Private consumption (CD)	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Field crop agriculture	3.9	2.1	3.9	2.1	3.4	2.4	0.0	0.0	2.4	-0.2	0.2	0.2
Hort. agriculture	-40.0	-55.5	-40.0	-55.3	-10.4	-36.9	-0.1	-0.4	-5.7	0.6	-0.4	-1.6
Livestock agriculture	7.2	16.5	7.2	16.4	1.7	10.6	0.0	0.1	0.8	-0.1	0.1	0.6
Homeland agriculture	6.3	20.8	6.3	21.0	5.6	19.4	0.0	0.0	0.0	0.0	9.1	9.1
Mining	-38.2	-33.8	-38.1	-33.5	-0.3	-0.3	-0.1	-0.1	-0.2	0.0	2.7	2.7
Manufacturing	-48.1	-39.7	-48.0	-40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Transport	-22.2	4.2	-22.2	4.1	0.2	0.4	0.1	0.1	0.1	0.1	0.1	0.2
Electricity and water	-40.8	-36.1	-40.0	-35.0	-0.2	-0.8	0.0	-0.2	-0.1	0.0	0.1	0.1
Construction	-7.0	-2.0	-6.9	-1.9	0.0	0.1	0.0	0.0	0.0	0.0	4.7	4.7
Services	4.8	-4.3	4.9	-4.2	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.2
	Price of:											
	Exports (E)		Imports (M)		Output (PX)		Dom. demand (PQ)		Dom. sales (PD)			
	High	Low	High	Low	High	Low	High	Low	High	Low		
Field crop agriculture	3.5	2.6	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1	-0.9	-0.7		
Hort. agriculture	-11.6	-40.9	0.9	2.4	0.9	4.6	0.5	1.9	4.4	20.2		
Livestock agriculture	1.9	12.2	-0.2	-0.5	-0.2	-0.9	-0.1	-0.5	-0.8	-4.4		
Homeland agriculture	6.9	24.1	-0.6	0.0	-0.6	-2.1	-0.3	-1.2	-3.5	-11.9		
Mining	-0.3	-0.3	0.0	-0.1	0.0	0.0	0.0	0.0	0.1	0.1		
Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Transport	0.2	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	-0.2		
Electricity and water	-0.3	-0.9	0.0	-0.1	0.0	0.1	0.0	0.1	0.1	0.4		
Construction	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1		
Services	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0		

Annex Table 4: Water use, land use and output changes with cuts in aggregate water supply under high and low factor substitution elasticities

	Base	-5%	-10%	-15%	-20%	-25%
Changes in water use under high factor substitution elasticities: (millions of cubic meters)						
Field crop agriculture	4.99	5.03	5.07	5.11	5.14	5.19
Horticultural agriculture	2.71	2.51	2.29	2.08	1.85	1.62
Livestock agriculture	0.50	0.51	0.52	0.52	0.53	0.54
Homeland agriculture	0.19	0.19	0.19	0.20	0.20	0.20
Mining	3.01	2.81	2.58	2.35	2.11	1.86
Manufacturing	2.51	2.27	2.01	1.77	1.53	1.30
Transport	0.03	0.02	0.02	0.02	0.02	0.02
Electricity and water	1.90	1.71	1.56	1.41	1.27	1.13
Construction	0.06	0.06	0.06	0.05	0.05	0.05
Services	0.02	0.02	0.02	0.02	0.02	0.02
Changes in water use under high factor substitution elasticities: (millions of cubic meters)						
Field crop agriculture	4.99	5.03	5.06	5.09	5.09	5.11
Horticultural agriculture	2.70	2.43	2.14	1.83	1.52	1.52
Livestock agriculture	0.50	0.51	0.52	0.54	0.56	0.56
Homeland agriculture	0.19	0.19	0.20	0.20	0.21	0.22
Mining	3.01	2.82	2.62	2.42	2.21	2.21
Manufacturing	2.53	2.29	2.08	1.89	1.70	1.70
Transport	0.02	0.03	0.03	0.03	0.03	0.03
Electricity and water	1.90	1.74	1.60	1.46	1.33	1.33
Construction	0.05	0.06	0.06	0.05	0.05	0.05
Services	0.02	0.02	0.02	0.02	0.02	0.02

(continued)

	Base	-5%	-10%	-15%	-20%	-25%
Changes in land use under high factor substitution elasticities: (millions of hectares)						
Field crop agriculture	3.06	3.08	3.11	3.13	3.15	3.18
Horticultural agriculture	0.19	0.18	0.16	0.15	0.13	0.11
Livestock agriculture	0.57	0.58	0.60	0.60	0.60	0.61
Homeland agriculture	0.41	0.14	0.14	0.15	0.15	0.15
Mining	0.16	0.15	0.14	0.13	0.11	0.10
Manufacturing	0.05	0.05	0.04	0.04	0.03	0.03
Transport	0.01	0.01	0.01	0.01	0.01	0.01
Electricity and water	0.02	0.02	0.02	0.02	0.01	0.01
Construction	0.01	0.01	0.01	0.01	0.01	0.01
Services	0.03	0.03	0.03	0.03	0.03	0.03
Changes in land use under high factor substitution elasticities: (millions of hectares)						
Field crop agriculture	4.99	5.03	5.06	5.09	5.09	5.11
Horticultural agriculture	2.70	2.43	2.14	1.83	1.52	1.52
Livestock agriculture	0.50	0.51	0.52	0.54	0.56	0.56
Homeland agriculture	0.19	0.19	0.20	0.20	0.21	0.22
Mining	3.01	2.82	2.62	2.42	2.21	2.21
Manufacturing	2.53	2.29	2.08	1.89	1.70	1.70
Transport	0.02	0.03	0.03	0.03	0.03	0.03
Electricity and water	1.90	1.74	1.60	1.46	1.33	1.33
Construction	0.05	0.06	0.06	0.05	0.05	0.05
Services	0.02	0.02	0.02	0.02	0.02	0.02

Annex Table 5: Land and water use in the Olifantsriver watershed

	(1) Land use (mill. ha)	(2) Percent of total	(3) Water use (mill. m3)	(4) Percent of total	(5) Water/ land ratio (m3/ha)
Field crop agriculture	3.06	72.2	500	31.1	163
Horticultural agriculture	0.19	4.5	270	16.8	1.421
Livestock agriculture	0.57	13.4	50	3.1	88
Homeland agriculture	0.14	3.3	19	1.2	136
Mining	0.16	3.8	300	18.6	1.875
Manufacturing	0.05	1.2	250	15.5	5.000
Transport	0.01	0.2	3	0.2	300
Electricity and water	0.02	0.5	192	11.9	9.600
Construction	0.01	0.2	6	0.4	600
Services	0.03	0.7	20	1.2	667
TOTAL	4.24	100.0	1.610	100.0	
	(1b)	(2b)	(3b)	(4b)	(5b)
Lands and Water Use in the Olifantsriver Watershed (used in sensitivity analysis towards initial water use assumptions)					
Field crop agriculture	3.06	72.2	500	31.1	163
Horticultural agriculture	0.19	4.5	270	16.8	1.421
Livestock agriculture	0.57	13.4	50	3.1	88
Homeland agriculture	0.14	3.3	15	0.9	107
Mining	0.16	3.8	300	18.7	1.875
Manufacturing	0.05	1.2	250	15.6	5.000
Transport	0.01	0.2	3	0.2	300
Electricity and water	0.02	0.5	192	12.0	9.600
Construction	0.01	0.2	6	0.4	600
Services	0.03	0.7	20	1.2	667
TOTAL	4.24	100.0	1,606	100.0	

Annex Table 6: Resource pull effects of a 25% cut in aggregate water supply under high and low Armington substitution elasticities

(percent change relative to base solution)

	Water demand		Land demand		Output (X)		Domestic demand (Q)		Domestic sales (D)		Private consumption (CD)	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Field crop agriculture	3.0	3.1	2.9	3.2	3.2	3.1	0.0	0.1	2.9	2.4	0.2	0.2
Hort. agriculture	-44.2	-39.2	-44.2	-38.9	-25.7	-17.5	0.2	-0.2	-16.4	-6.4	-0.8	-0.8
Livestock agriculture	11.3	10.0	11.5	9.9	6.4	3.8	0.1	0.1	3.6	1.3	0.4	0.4
Homeland agriculture	11.1	8.3	11.3	8.4	8.3	8.3	0.0	0.0	0.0	0.0	9.1	9.1
Mining	-34.9	-36.7	-34.8	-36.6	-0.4	-0.5	-0.1	-0.1	-0.3	-0.2	2.7	2.7
Manufacturing	-48.3	-50.2	-48.0	-50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Transport	-12.5	-12.5	-12.5	-12.5	0.4	0.4	0.1	0.1	0.2	0.1	0.2	0.2
Electricity and water	-38.3	-40.0	-39.0	-40.0	0.5	-0.5	-0.1	-0.1	-0.2	-0.1	0.3	0.3
Construction	-22.0	-24.0	-22.0	-24.0	0.1	0.1	0.0	0.0	0.0	0.0	7.0	9.3
Services	13.0	13.0	13.0	13.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2

	Price of:											
	Exports (E)		Imports (M)		Output (PX)		Dom. demand (PQ)		Dom. sales (PD)			
	High	Low	High	Low	High	Low	High	Low	High	Low		
Field crop agriculture	3.4	3.2	-0.2	-0.1	-0.1	-0.2	0.0	-0.1	-0.5	-1.2		
Hort. agriculture	-28.1	-20.4	1.8	0.5	2.3	2.5	1.0	1.2	10.4	11.5		
Livestock agriculture	7.1	4.6	-0.4	-0.1	-0.4	-0.4	-0.2	-0.2	-2.0	-2.0		
Homeland agriculture	10.3	10.3	0.0	0.0	-1.0	-1.3	-0.6	-0.7	-5.7	-7.3		
Mining	-0.4	-0.5	-0.1	-0.1	0.0	0.0	0.0	0.0	0.1	0.2		
Manufacturing	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Transport	0.5	0.5	0.1	0.1	0.0	0.0	0.0	0.0	-0.1	-0.1		
Electricity and water	-0.6	-0.6	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.3		
Construction	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0		
Services	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0		

Annex Table 7: Partial equilibrium estimates of sectoral supply and demand elasticities

	(1) Factor substitution elasticity	(2) Labor share	(3) Land share	(4) Capital share	(5) Land/ labor	(6) Land/ capital
Field crop agriculture	0.60	0.58	0.19	0.24	0.32	0.79
Horticultural agriculture	0.90	0.61	0.09	0.29	0.15	0.33
Livestock agriculture	0.90	0.62	0.08	0.30	0.13	0.26
Homeland agriculture	0.60	0.53	0.23	0.25	0.43	0.91
Mining	0.90	0.72	0.03	0.25	0.03	0.10
Manufacturing	0.90	0.82	0.01	0.17	0.02	0.08
Transport	0.50	0.82	0.01	0.17	0.01	0.04
Electricity and water	0.50	0.72	0.02	0.26	0.03	0.08
Construction	0.25	0.88	0.01	0.11	0.01	0.07
Services	0.25	0.85	0.01	0.15	0.01	0.03

	(7) CD	(8) Theta	(9) ID	(10) Q	(11) Sectoral demand elastici-ties	
Field crop agriculture	0.887	0.00	0.04	2.478	0.36	
Horticultural agriculture	0.252	0.00	0.03	11.331	0.02	
Livestock agriculture	0.689	0.00	0.07	3.642	0.19	
Homeland agriculture	0.011	0.00	0.00	0.068	0.16	
Mining	0.037	-0.08	-1.27	5.798	0.02	
Manufacturing	13.501	0.15	1.87	53.475	0.26	
Transport	3.671	0.02	0.28	7.859	0.47	
Electricity and water	15.260	-0.01	-0.11	5.726	2.67	
Construction	0.043	0.86	6.83	9.265	0.64	
Services	12.061	0.91	7.00	35.873	0.51	

Legend: Column 1 = Factor substitution elasticities used in water demand and water/land reform experiments; Column 2 = Labor share in CES production function: Column 3 = Land-water aggregate share in CES production function: Column 4 = Capital share in CES production function: Column 5 = Ratio of Column 3 and Column 2: Column 6 = Ratio of Column 3 and Column 4: Column 7 = Private consumption: Column 8 = Sectoral investment as a share of total investment: Column 9 = Sectoral investment: Column 10 = Domestic demand: Column 11 = Elasticity of demand = (Column 7 + Column 8 * Column 9) / Column 10.

Source: Dervis, de Melo and Robinson. 1982. pp. 264-5.

	Sectoral supply elasticities with respect to	
	(7) Column 5	(8) Column 6
Field crop agriculture	0.19	0.47
Horticultural agriculture	0.14	0.29
Livestock agriculture	0.11	0.24
Homeland agriculture	0.26	0.54
Mining	0.03	0.09
Manufacturing	0.01	0.07
Transport	0.00	0.02
Electricity and water	0.01	0.04
Construction	0.00	0.02
Services	0.00	0.01

[illegible] = Column 1 * Column 6

Annex Table 8: Water use, land use and output changes with cuts in aggregate water supply under high and low Armington substitution elasticities

	Base	-5%	-10%	-15%	-20%	-25%
Changes in water use under high Armington substitution elasticities: (millions of cubic meters)						
Field crop agriculture	4.99	5.03	5.06	5.10	5.12	5.14
Horticultural agriculture	2.71	2.49	2.27	2.02	1.77	1.51
Livestock agriculture	0.50	0.51	0.52	0.53	0.54	0.56
Homeland agriculture	0.19	0.19	0.19	0.20	0.20	0.21
Mining	3.02	2.82	2.62	2.41	2.19	1.96
Manufacturing	2.52	2.25	1.99	1.75	1.52	1.31
Transport	0.02	0.02	0.02	0.02	0.02	0.02
Electricity and water	1.89	1.74	1.58	1.44	1.30	1.17
Construction	0.05	0.05	0.05	0.04	0.04	0.04
Services	0.02	0.02	0.02	0.02	0.03	0.03
Changes in water use under low Armington substitution elasticities: (millions of cubic meters)						
Field crop agriculture	4.99	5.02	5.06	5.10	5.13	5.14
Horticultural agriculture	2.71	2.52	2.32	2.11	1.88	1.65
Livestock agriculture	0.50	0.51	0.51	0.52	0.54	0.55
Homeland agriculture	0.19	0.19	0.20	0.20	0.20	0.21
Mining	3.02	2.81	2.60	2.38	2.15	1.91
Manufacturing	2.52	2.24	1.97	1.71	1.48	1.26
Transport	0.02	0.02	0.02	0.02	0.02	0.02
Electricity and water	1.89	1.73	1.57	1.42	1.28	1.34
Construction	0.05	0.05	0.05	0.04	0.04	0.04
Services	0.02	0.02	0.02	0.02	0.03	0.03

Note: Base solution is slightly different from Table 5.5.

(continued)

	Base	-5%	-10%	-15%	-20%	-25%
Changes in land use under high Armington substitution elasticities: (millions of hectares)						
Field crop agriculture	3.05	3.08	3.10	3.19	3.13	3.14
Horticultural agriculture	0.19	0.18	0.16	0.14	0.13	0.11
Livestock agriculture	0.57	0.58	0.59	0.60	0.62	0.64
Homeland agriculture	0.14	0.14	0.15	0.15	0.15	0.16
Mining	0.16	0.15	0.14	0.13	0.12	0.11
Manufacturing	0.05	0.05	0.04	0.04	0.03	0.03
Transport	0.01	0.01	0.01	0.01	0.01	0.01
Electricity and water	0.02	0.02	0.02	0.02	0.01	0.01
Construction	0.01	0.01	0.01	0.01	0.01	0.01
Services	0.04	0.04	0.04	0.04	0.04	0.04
Changes in land use under low Armington substitution elasticities: (millions of hectares)						
Field crop agriculture	3.05	3.08	3.10	3.12	3.14	3.15
Horticultural agriculture	0.19	0.18	0.16	0.15	0.13	0.12
Livestock agriculture	0.57	0.58	0.59	0.60	0.61	0.63
Homeland agriculture	0.14	0.15	0.15	0.15	0.15	0.16
Mining	0.16	0.15	0.14	0.13	0.11	0.10
Manufacturing	0.05	0.05	0.04	0.03	0.03	0.03
Transport	0.01	0.01	0.01	0.01	0.01	0.01
Electricity and water	0.02	0.02	0.02	0.02	0.01	0.01
Construction	0.01	0.01	0.01	0.01	0.01	0.01
Services	0.04	0.04	0.04	0.04	0.04	0.04

(continued)

	Base	-5%	-10%	-15%	-20%	-25%
Changes in output under high Armington substitution elasticities: (billions of Rand)						
Field crop agriculture	1.01	1.02	1.02	1.03	1.04	1.04
Horticultural agriculture	0.69	0.66	0.63	0.60	0.56	0.51
Livestock agriculture	1.88	1.89	1.91	1.93	1.96	2.00
Homeland agriculture	0.04	0.04	0.04	0.04	0.04	0.04
Mining	12.34	12.34	12.34	12.32	12.31	12.29
Manufacturing	57.46	57.46	57.46	57.46	57.46	57.46
Transport	7.75	7.75	7.76	7.76	7.77	7.78
Electricity and water	7.85	7.84	7.84	7.83	7.82	7.81
Construction	9.78	9.78	9.78	9.78	9.78	9.78
Services	44.78	44.79	44.79	44.80	44.81	44.82
Changes in output under low Armington substitution elasticities: (billions of Rand)						
Field crop agriculture	1.01	1.01	1.02	1.03	1.03	1.04
Horticultural agriculture	0.69	0.67	0.65	0.63	0.60	0.57
Livestock agriculture	1.88	1.89	1.90	1.91	1.93	1.95
Homeland agriculture	0.04	0.04	0.04	0.04	0.04	0.04
Mining	12.34	12.34	12.33	12.32	12.30	12.28
Manufacturing	57.46	57.46	57.46	57.46	57.46	57.46
Transport	7.75	7.75	7.76	7.76	7.77	7.78
Electricity and water	7.85	7.84	7.84	7.83	7.82	7.81
Construction	9.78	9.78	9.78	9.78	9.78	9.79
Services	44.78	44.79	44.79	44.80	44.81	44.82

Annex Table 9: Implicit factor and subfactor use assumptions used in the Social Accounting Matrix

	(1) Land use (mill. ha)	(2) Water use (mill. m3)	(3) Price of land (R/ha)	(4) Price of water (R/ha)	(5) = (1) * (3) Value of land (bill. R)	(6) = (2) * (4) Value of water (bill. R)	(7) = (5) + (6) Value of land-water aggregate (bill. R)
Field crop agriculture	3.06	500.00	50.00	0.03	0.153	0.015	0.168
Horticultural agriculture	0.19	270.00	50.00	0.03	0.010	0.008	0.018
Livestock agriculture	0.57	50.00	50.00	0.03	0.029	0.002	0.030
Homeland agriculture	0.14	18.75	50.00	0.03	0.007	0.001	0.007
Mining	0.16	300.00	50.00	0.03	0.008	0.009	0.017
Manufacturing	0.05	250.00	50.00	0.03	0.003	0.008	0.010
Transport	0.01	3.00	50.00	0.03	0.000	0.000	0.000
Electricity	0.02	192.00	50.00	0.03	0.001	0.006	0.007
Construction	0.01	6.00	50.00	0.03	0.000	0.000	0.000
Services	0.03	20.00	50.00	0.03	0.001	0.002	0.002
	(8) GOS[a] from IO tables (bill. R)	(9) = (8) - (7) Resultant capital (bill. R)	(10) = (5)/(7) Percent of land in land-water aggregate	(11) = (6)/(7) Percent of water in land-water aggregate	(12) = (9)/(8) Percent of capital in GOS	(13) = (7)/(8) Percent of land water aggregate in GOS	
Field crop agriculture	0.47	0.30	0.91	0.09	0.64	0.36	
Horticultural agriculture	0.32	0.30	0.54	0.46	0.94	0.06	
Livestock agriculture	0.87	0.84	0.95	0.05	0.97	0.03	
Homeland agriculture	0.02	0.01	0.92	0.08	0.56	0.44	
Mining	5.66	5.64	0.48	0.52	1.00	0.00	
Manufacturing	6.55	6.54	0.27	0.73	1.00	0.00	
Transport	2.11	2.11	0.75	0.25	1.00	0.00	
Electricity	3.33	3.32	0.12	0.88	1.00	0.00	
Construction	0.41	0.41	0.60	0.40	1.00	0.00	
Services	7.64	7.64	0.69	0.31	1.00	0.00	

[a] Gross operating surplus - value-added paid out to non-labor factors (capital and land-water aggregate).

Note: Percent based on monetary values, not physical amounts.

Annex Table 10: Output and export changes with cuts in aggregate water supply under different water and land prices

	(Price of land = 50R/ha)		(Price of water = 0.03R/m3)	
	Price of water (Rand/m3)		Price of land (Rand/ha)	
	0.02	0.01	40.00	30.00
Changes in output under different water and land prices: (percentage change relative to base)				
Field crop agriculture	0.10	0.00	-0.10	-0.10
Horticultural agriculture	0.00	-0.10	-0.10	-0.10
Livestock agriculture	0.00	2.90	2.90	2.90
Homeland agriculture	0.00	0.00	0.00	0.00
Mining	0.00	0.00	0.00	0.00
Manufacturing	0.00	0.00	0.00	0.00
Transport	0.00	0.00	0.00	0.00
Electricity	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Services	0.00	0.00	0.00	0.00
Changes in exports under different water and land prices: (percentage change relative to base)				
Field crop agriculture	0.10	0.10	0.00	0.00
Horticultural agriculture	-0.20	0.00	0.00	0.00
Livestock agriculture	0.00	0.00	0.00	-0.10
Homeland agriculture	0.00	0.00	3.40	0.00
Mining	0.00	0.00	0.00	0.00
Manufacturing	0.00	0.00	0.00	0.00
Transport	0.00	0.00	0.00	0.00
Electricity	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Services	0.00	0.00	0.00	0.00

Annex Table 11: Water use changes with cuts in aggregate water supply under different water and land prices
(percentage change relative to base)

	(Price of land = 50R/ha)		(Price of water = 0.03R/m3)	
	Price of water (Rand/m3)		**Price of land (Rand/ha)**	
	0.02	**0.01**	**40.00**	**30.00**
Field crop agriculture	0.20	0.10	-0.10	-0.20
Horticultural agriculture	0.10	0.50	-0.30	-0.30
Livestock agriculture	0.00	0.00	-0.40	-0.40
Homeland agriculture	0.00	2.20	2.70	3.20
Mining	0.20	0.80	-0.30	-0.20
Manufacturing	4.00	2.10	0.40	-0.50
Transport	-19.00	-14.30	-9.50	14.30
Electricity	-0.70	-4.40	0.40	1.80
Construction	-11.00	-24.40	-4.40	-13.30
Services	-8.00	-16.00	4.00	12.00

Annex Table 12: Effects of 75% water curtailment under varying 'homeland' water use assumptions

	Water demand	Output
Initial homeland water use assumption of 18 million cubic meters (percent change relative to base solution)		
Field crop agriculture		
Horticultural agriculture	-61.40	-50.30
Livestock agriculture	-91.00	-39.30
Homeland agriculture	21.00	22.60
Mining	-54.30	-45.70
Manufacturing	-87.80	0.50
Transport	-91.90	-0.20
Electricity and water	-44.00	1.20
Construction	-76.20	-3.00
Services	-32.70	0.30
	9.50	0.20
Initial homeland water use assumption of 18 million cubic meters (percent change relative to base solution)		
Field crop agriculture		
Horticultural agriculture	-65.60	-54.90
Livestock agriculture	-89.00	-38.80
Homeland agriculture	-16.50	6.00
Mining	1458.30	1245.00
Manufacturing	-84.90	0.70
Transport	-88.90	-0.40
Electricity and water	-40.00	1.10
Construction	-72.80	-2.10
Services	-30.90	0.20
	0.00	0.20